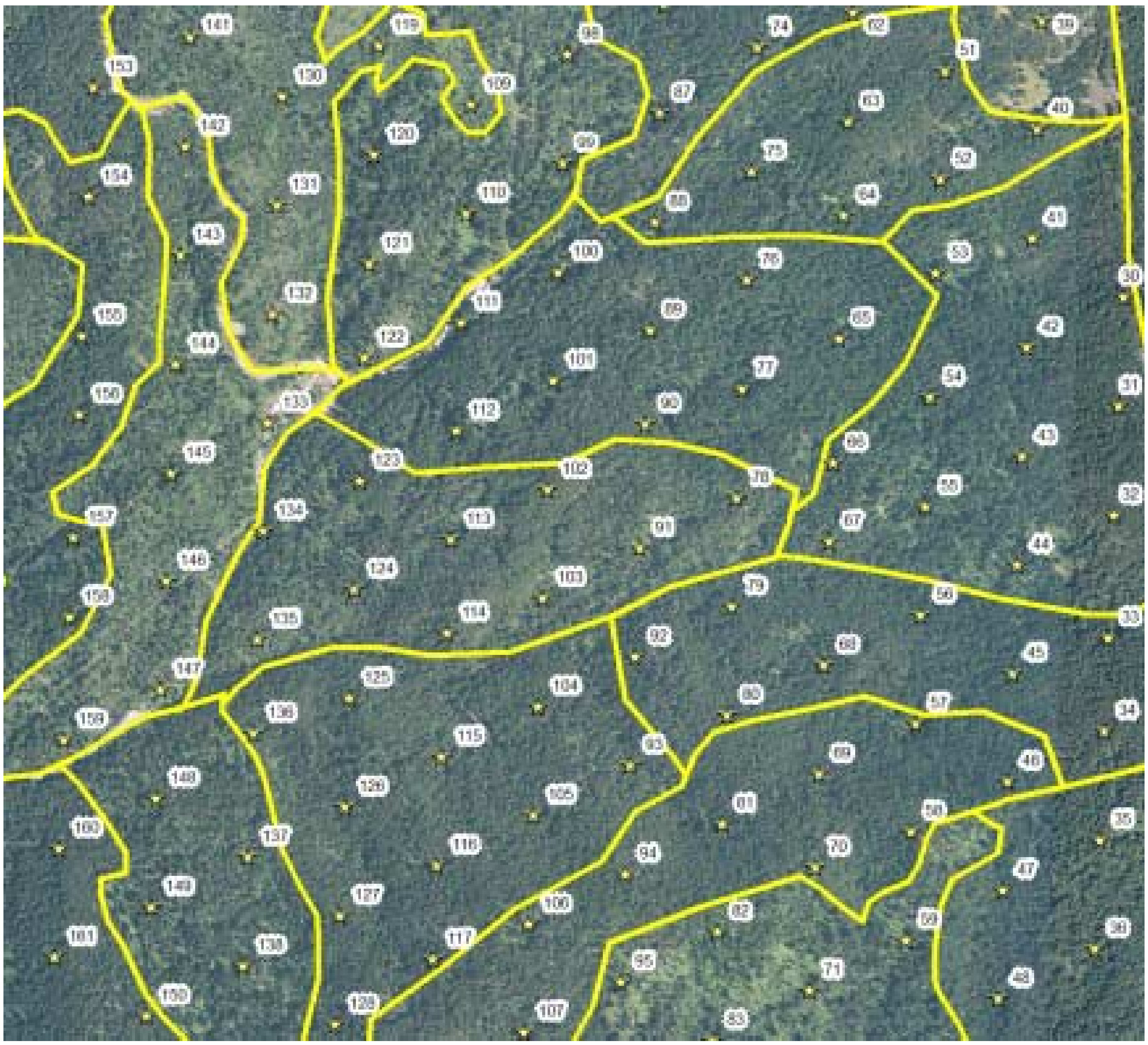
Recommendations on Sampling Design and Scope of Work for Forest Health Assessments Conducted by Washington State Parks



Pacific Biodiversity Institute

Recommendations on Sampling Design and Scope of Work for Forest Health Assessments Conducted by Washington State Parks

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Introduction

In May 2007, Pacific Biodiversity Institute (PBI) completed a forest inventory of sections of Mt. Spokane State Park (Spokane County, WA) using methods and protocols specified in the contract containing a scope of work (SOW) written by Washington State Parks staff (Morrison et al. 2007). Significant insights were developed by PBI staff during implementation of the SOW on how to improve the efficiency and quality of the forest stand survey procedures. This report covers a variety of topics ranging from initial study design and sampling design to the details of data collection for specific stand attributes. The report builds on the insights we gained from the Mt. Spokane project. It is our hope that State Park staff will find this report helpful in developing a more detailed and effective scope of work documents for future projects of a similar nature.

Modifications to Sampling Design

In this section, we discuss potential modifications to the basic sampling design that was used in the Mt. Spokane project. We discuss sampling type, sample size, plot type and plot size, which are related. Trade-offs in terms of cost, level of detail, geographic coverage, and other factors need to be considered. Different sample designs provide advantages and disadvantages that should be weighed in relation to short- and long-term goals. Goals of forest description and mapping, monitoring, habitat assessment, and other analyses may best be met through different sampling schemes. Clearly defining short- and long-term goals and priorities for data collection is the first, and most important, step in sample design.

Sample type

Common sample designs for forest data collection are: 1) systematic and 2) random. For heterogeneous environments, stratified sampling (either stratified random or stratified systematic) is often used. Another method that has been used is choosing plot locations based on subjective judgment of representative sites by an experienced ecologist. We discuss the advantages and disadvantages of these methods below.

Systematic versus random sampling

In the Mt. Spokane project, we used a systematic sample design laid out in an offset grid with plots every 10 acres. It was based on sample locations established by Washington Department of Natural Resources (DNR). DNR's systematic plot layout was useful in many regards. It ensured that the entire area was thoroughly surveyed. It proved to be conducive to the inverse distance weighted (IDW) interpolation that we eventually applied to the summarized plot data. It could be useful for providing verifiable local information (for example, checking accuracy of forest maps) since much of the ground is covered. However, it is very labor intensive and more efficient plot layouts may yield better information with less cost. Another criticism is that systematic sampling may sometimes interact with patterns in the landscape leading to unrepresentative data (e.g. a ridge and valley system where the top of the ridge is always sampled because of its alignment with the grid). In addition, we found that long, thin forest stands (polygons)

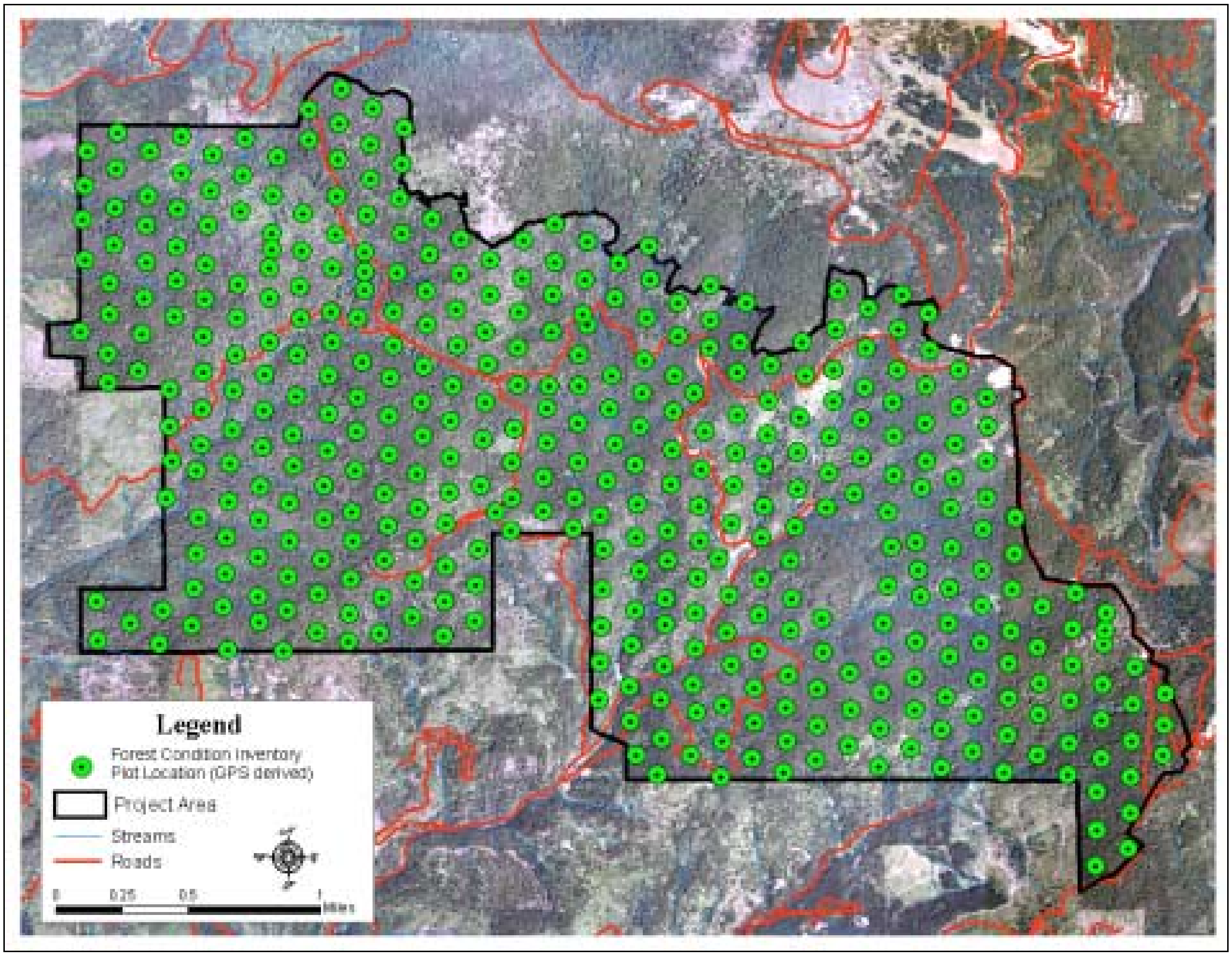

Figure 1. Plot locations on a systematic grid in the Mt. Spokane project area. The unsampled area in the central eastern part of the project area is a private inholding. Also visible are places were we had to move plots off the systematic grid because plots fell on polygon boundary or roads.

and small stands (polygons) are often inadequately sampled with this method. In the Mt. Spokane project we often found that plots established on the grid fell on stand boundaries. In these cases, it was necessary to move the plot so that it was contained entirely within one stand. In other cases, plots fell on features such as roads that were not intended to be sampled. Again, it was it was necessary to move the plot. Rules can be established to handle these situations, but they can be difficult to implement.

Random sampling is the most statistically rigorous method since statistical tests usually have a random data assumption. However, getting to random sites often requires great effort. For purely descriptive purposes, random data collection may not be necessary or worth the cost.

Stratified sampling

Stratified sampling provides advantages for heterogeneous environments and is commonly used for forest data collection. The landscape is divided into more homogeneous units, and sampling is conducted within each of these units or strata. For the state parks, strata could be identified and mapped in advance through a combination of aerial photo interpretation and modeling. Each stratum would likely consist of multiple polygons. Within each stratum, plot locations can be randomly or systematically assigned.

Stratified random sampling is most commonly employed in forest studies and provides the advantage of greater statistical rigor over stratified systematic sampling. The number of plots is determined on a per-strata basis, with more plots allocated for more heterogeneous units and less plots for more homogeneous units. The result is greater data precision that can be accomplished, given an equal number of plots, through either pure systematic or pure random sampling.

In order to ensure that all polygons within a stratum are sampled, a modified random approach could be used. The appropriate density or total number of plots per stratum could be assigned on the basis of heterogeneitywithin the stratum and the number of plots within a polygon assigned proportionally according to polygon size. The designated number of plots can then be randomly placed in the polygon. In addition, a set of rules could be developed and implemented in a GIS environment to avoid inappropriate plot locations (e.g. a minimum distance from a polygon's edge).

Disadvantages to stratified random sampling are that mapping the strata takes additional effort, preliminary work needs to be done to estimate heterogeneity of strata, and data analysis can be more complex. Assuming the strata are meaningful units however, this method provides potentially useful data that can be analyzed on a per-strata basis.

Mapping of strata could be accomplished through modeling based on imagery, topographic information, and other available data. A preliminary, quick reconnaissance survey would provide valuable information and aid in mapping.

Selection of representative plots sampling

Vegetation ecologists have often used a method of plot selection where they select representative plots to describe various forest conditions "selectively without preconceived bias" (Mueller-Dombios and Ellensburg 1974, Williams and Lillybridge 1983, Lillybridge et al. 1995, Williams et al. 1995, Morrison and Snetsinger 2003, Morrison et al. 2003). This method of plot selection has distinct advantages and disadvantages over other plot selection methods. It can be much less time consuming than random or systematic sampling techniques. An experienced ecologist should be able to characterize the ecological condition of a forest through careful selection of plots using this method. It can result in excellent descriptive data and has been used by many US Forest Service ecologists to describe and characterize the plant associations of various national forests. The downside of this method is that it is subjective and statistical analysis cannot be validly applied to the resulting data. Therefore, it has limited usefulness in complex analysis.

Sample size

The level of sampling required in the SOW for the Mt. Spokane project in terms of the number of plots per acre seemed excessive. Previous field inventory experience led us to believe that less field sampling could be done while still preserving the integrity and detail of the data collected. The original SOW called for plots to be surveyed at a frequency of 1 plot for every 10 acres, and for those plots to be distributed in a systematic grid across the project area. This approach is conservative in terms of producing highly descriptive and statistically valid datasets, but it created significant extra labor and cost demands on the project that could have been strategically reduced without harming the integrity of the data.

Sample size affects data accuracy - greater sample size leads to greater accuracy. However, there are obvious trade-offs of cost and effort, and the level of detailed information that can be collected at each plot. Appropriate sample sizes can be objectively determined based on the estimated variance of a given variable and a desired confidence interval for that variable.

Project managers will need to determine a small suite of variables on which to base sample size estimates. It is not necessary or desirable to consider every variable for determining an appropriate sample size. Variables for sample size consideration should be prioritized based on their importance in accomplishing project goals.

A table showing correlations of variables in the Mt. Spokane area is included as Appendix A. It is unknown whether these relationships would hold in other environments, but at least for Mt Spokane they can be used as one tool to help prioritize variables for determining sample size. For example, if there are a couple of variables of importance to the project, but one of those is highly correlated with other high priority variables, it might be wise to choose the less correlated variable for sample size consideration.

Project managers will need to evaluate the trade-offs in cost and data precision requirements to determine appropriate confidence intervals for variables. For example, if the primary purpose of data collection is prioritizing stands for treatments and a wider range in data values for a given variable seems unlikely to notably shift priorities, it would be cost-effective to set a wide confidence interval. Exact trade-offs cannot be evaluated however, without doing some initial analysis. If the data is to be used in a primarily descriptive manner, an 80% confidence interval might be a reasonable basis for initial investigation.

Several avenues may be possible for estimating variances, which are needed to determine sample size. In some cases, previous data may have been collected in the same park or a comparable park for particular vegetation types. Sample sizes can be calculated based on variances calculated from the previously studied sites. If no previous data exists then an initial data collection effort may be necessary. Random plot locations could be generated for each stratum, with the number of initial plots based on an assessment of the likely degree of heterogeneity from image interpretation. This might range from 7 (mostly homogenous) to 20 (highly heterogenous) plots per stratum (and randomly assigned in the stratum as a whole, rather than to individual polygons/stands that make up that stratum). Data collected at these plots could be used to estimate variances of key variables. These data could also be included as part of the main study data and so in that sense would not be wasted effort.

Variances and a confidence interval would be used to estimate sample size. This sample size could be assigned to the mean polygon size within that stratum and an appropriate density of plots per acre calculated, which would then be applied to all stands/polygons within the stratum.

In conducting an initial survey, the goal is to get a reasonably good estimate of variances with the minimum number of initial plots. One method that could be helpful in making an initial assessment of plot numbers for the purpose of estimating variances is illustrated in Appendix B. We conducted a resampling exercise and looked at trade-offs of sample size and data precision. For the relatively homogenous polygons we examined there appeared to be a point of diminishing returns in terms of decreasing variance at a sample size of around 7 plots (varying somewhat however, among 16 different variables). Similar methods could be used to assess trade-offs for more heterogeneous stands. Sample sizes for initial data collection (i.e. for estimating variances) could be broadly based on very general assessments such as these, for strata thought to contain similar levels of variance.

Plot type and size

The type of plot used and the size of the plot are interrelated factors that need to be considered when determining optimal sample design for forest health assessments. In addition, the trade-offs between level of effort expended to reach plot locations versus the amount of data collected at a given location should be evaluated.

Plot type

Single point plots were used in the Mt. Spokane project. Considerable effort was spent getting to the plots, which sometimes did not appear particularly representative of the stand. A slight movement in any direction would have yielded significantly different data at some plots. This is due to high micro-scale variability within many stands.

An alternative to single point plots is a ten-point cluster plots (Figure 2). The US Forest Service has used ten point cluster plots for most of its timber inventories and five point cluster plots for some of its forest ecology intensive plots. This clustering of plots can yield much better information about stand characteristics and variability at a macro plot level. Data from each point in the cluster are averaged together, with the mean values representing a single plot. A disadvantage is that data collection at each plot site takes longer. But this can be offset by the need for many fewer cluster plots compared to single point plots laid out on a systematic grid. Cluster plots reduce the amount of variance between plots, thereby reducing overall the number of plots necessary to achieve particular data precision standards. The biggest time and cost savings come from reduction in travel time. Forest survey crews would need to travel to fewer locations.

Once they are at the cluster plot location, it is only a short distance to each of the 10 points.

More recently, the Forest Inventory and Analysis program of the US Forest Service adopted a new national plot design in the mid-1990's. Now all FIA units have implemented a common sampling design consisting of four 24.0-foot radius subplots (each subplot is approximately 1/24th acre) for trees at least 5 inches in diameter and four 6.8-foot radius microplots (each microplot is approximately 1/300th acre) for smaller trees (Figure 3). Therefore, tree expansion factors are approximately 6 for trees at least 5 inches in diameter and approximately 75 for the smaller trees. Subplot 1 is the center of the cluster with the other three subplots located 120 feet away at azimuths of 360°, 120°, and 240°, respectively. This new plot design is describe in depth by Bechtold and Patterson (2005).

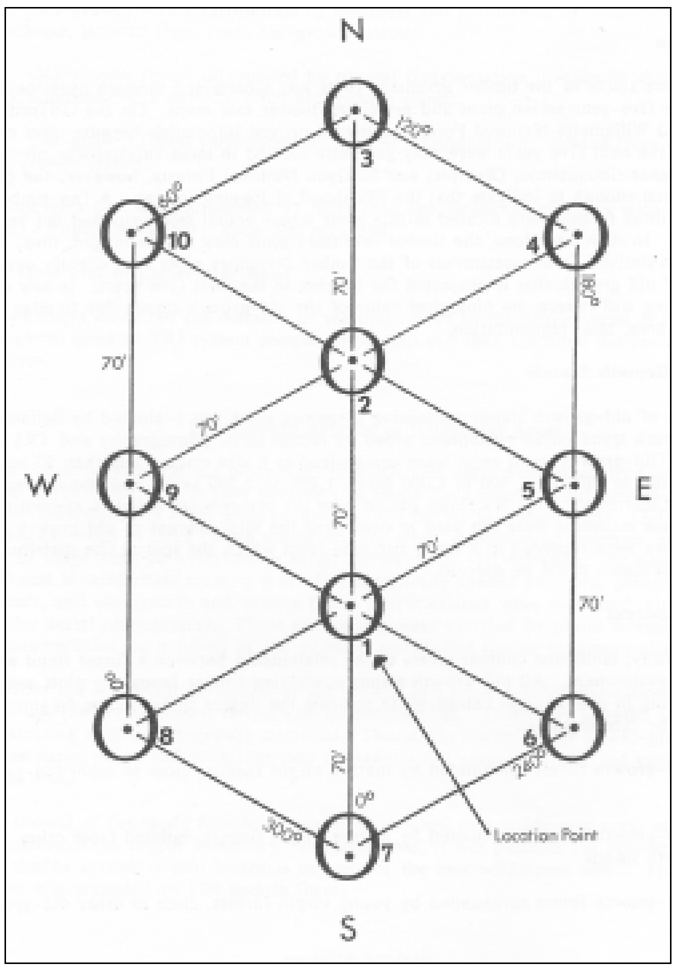

Figure 2. Layout of 10-point cluster plot used in timber inventories of National Forests in Oregon and Washington (USDA Forest Service 1980).

The new FIA plots have several advantages. They are entirely fixed radius plots and do not have some of the issues associated with variable radius plots. They are designed to collect the kinds of data that we collected in the Mt. Spokane project and would incorporate improvements that we discuss below. We recommend that future projects explore the use of the new FIA plot design and layout.

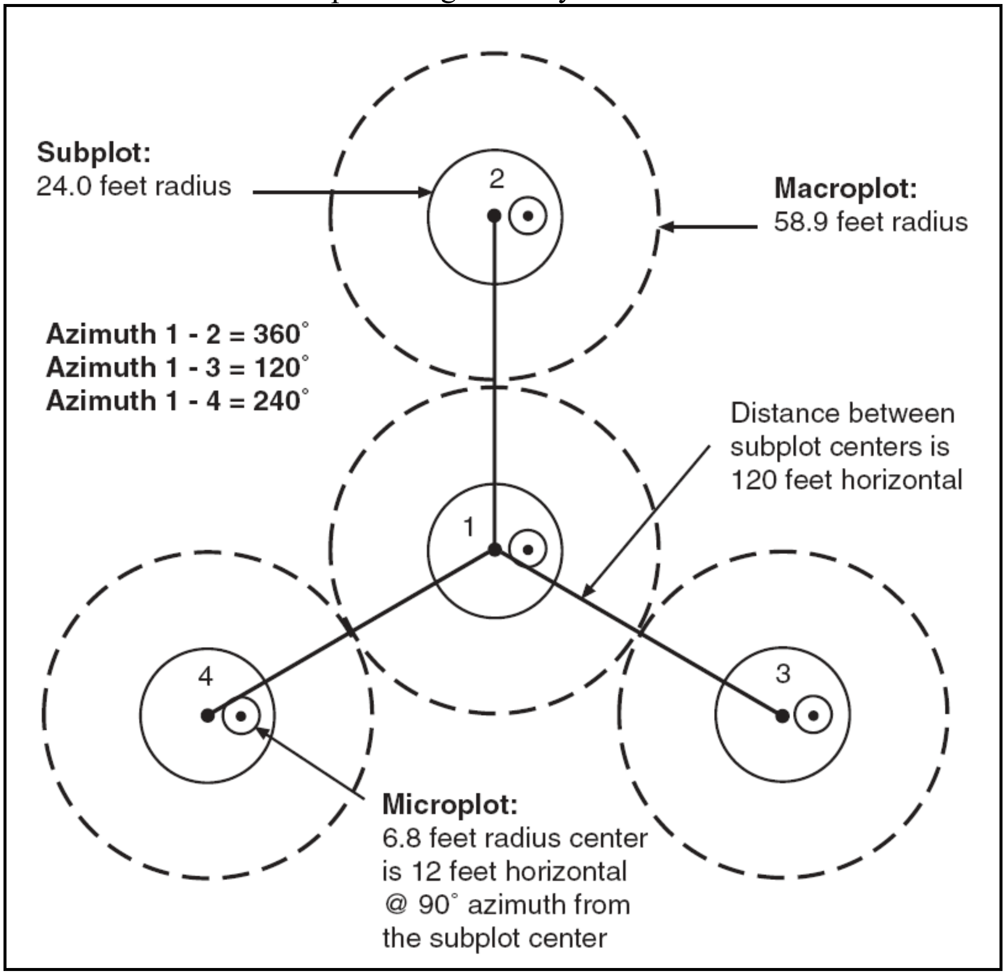

Figure 3. New FIA plot design.

Plot Size

The original RFP for the Mt. Spokane project called for the use of a combination of variable radius plots and fixed radius plots. The variable radius plots were to be determined by a Basal Area Factor (BAF) of 10. We recognized that in many cases the forests at Mt. Spokane are too dense and have too much basal area to be reliably and efficiently sample at a BAF of 10. So we modified the variable radius sampling procedure as follows: "We collected data on all the stand attributes specified in our contract using a combination of fixed (0.05 acre) and variable radius plots. A detailed description of the sampling methods is outlined below. For the variable radius plots, we used an appropriate Basal Area Factor (BAF) for each stand condition that we encountered. Our default BAF was 10. We used a BAF of 20 if a BAF of 10 pulled in more than 15 trees into a plot. In a few plots, a BAF of 40 was used if greater than 15 trees were in the plot using a BAF of 20" (Morrison et al. 2007).

For future projects of a similar nature, we recommend that variable radius plots follow similar rules. In drier, more open forests a BAF of 10 may be uniformly used. The use of variable BAFs to select measurement trees based on a cut-off amount of trees captured within a plot, could use a different cut-off value than 15. If a more rigorous sample is desired, the cut-off value could be increased to 20. If minimizing cost and time are factors, a cut-off value of 10 may be more appropriate. If the sampling design changed from single point plots, such as used at Mt. Spokane, to a ten point cluster plot, as illustrated above, a lower cut of value closer to 10 would be appropriate. This would probably entail the use of a higher basal area factor for cluster plots than for single point plots.

We found that the plot size of the fixed radius plot ($1/20^{th}$) acre was adequate for the sampling that we did in the Mt. Spokane project area. We recommend keeping this sampling parameter unchanged. If the plot design is change to the FIA plot design that we have discussed above, then the fixed radius plots size would also change.

Stand Delineation

The original SOW required the delineation of forest stands of a specified size range prior to ground surveys using aerial imagery and digital topographic data. Delineated stands were specified by the scope of work to fall within the range of 75-125 acres and be composed of relatively homogenous conditions (species composition, age, structure, understory vegetation, physical attributes, and slope). We found that many stands only expressed homogeneous conditions throughout areas considerably less than 75 acres and that some stands were relatively homogeneous throughout areas more than 125 acres. Therefore the size constrictions for stand delineation did not work well for us at Mt. Spokane.

It should be determined prior to initiating another project what the objectives are for the delineated stands. For the purpose of determining forest health conditions, it would be better to not have size constrictions, but to let the actual conditions found on the project area determine the eventual stand sizes that are delineated. This will result in more meaningful stand delineation. If the object of a size constraint on stand delineation is to be able to use the delineated stands as boundaries of potential treatment units, then this objective can be best accomplished through other means. Treatment unit boundaries need to consider many other factors that may not match stand boundaries that are delineated based on relatively homogenous forest conditions. In the Mt. Spokane project, we ended up delineating treatment boundaries that resulted from subdivision of stands, crossed stand boundaries into adjacent stands, or coincided exactly with the stands that we delineated, depending on conditions at the site and the objectives and constraints of the treatment units. Our recommendation is to keep delineation of stand boundaries and treatment unit boundaries separate and not to try to accomplish both in the same process. This will result in more objective and meaningful stand boundaries and more practical treatment unit boundaries.

In future projects of this nature, we recommend that only very obvious stand boundaries be mapped prior to visiting a project area and that these be mapped regardless of size constraints. We recommend a quick reconnaissance survey be conducted prior to comprehensive stand mapping by a competent ecologist. During initial survey, quick reconnaissance ecology plot data could be collected (Williams and Lillybridge 1983, Lillybridge et al. 1995, Williams et al. 1995, Morrison and Snetsinger 2003) for the sole purpose of plant community description and mapping. After the reconnaissance survey, comprehensive stand mapping could be done using the reconnaissance plot data, an initial evaluation of plant communities, aerial photography, topographic information and ancillary GIS layers. This will provide a much sounder basis for stand delineation. Subsequent modification of stand boundaries would also be possible after more intensive fieldwork was conducted, but we expect that the modifications would be slight. Using this method, the final stand map will be much more useful in evaluating forest health condition and in subsequent development of forest health treatments.

Modifications to Forest Survey Data Collected Within Each Plot

Field season for sampling

Due to contract constraints, the bulk of the survey work at Mt. Spokane was done during October 2006. This was not the optimal time for this work. Many plants were either dry or losing their leaves (or both), making plant identification more difficult. Low light levels in October made photography and, in some cases, visibility more difficult. In contrast, we did one week of forest surveys in the end of May 2007. This work went more quickly as a result of better weather, longer day length and resulted in better data due to more optimal plant phenology.

We recommend that future forest survey work be conducted during the months of May through September. This should lower costs somewhat and improve the quality of the work.

Plot photos

We recommend adding one photo per plot of the canopy. The addition of a wide-angle photo looking up at the canopy would better characterize the plot.

There were some problems with photos collected by another contractor that used cheap, disposable film cameras in the Mt. Spokane project (fogging lenses and poor lighting). Relatively good digital cameras should be required that operate at relatively low light levels under a forest canopy.

Forest canopy cover data

In the Mt. Spokane project, densiometers were use to measure forest canopy cover. Four densiometer readings were taken at the center of the plot in four cardinal directions. However, often the canopy cover at the plot center was not necessarily characteristic of the surrounding stand. Additional densiometer readings would have given a better characterization of the canopy cover of the stand. If future project timelines and budgets allow, we recommend collection of densitometer readings in at least 2 more locations per plot (3 locations total) and average the readings per plot (Figure 3). This should give us a better canopy cover value, especially in more open or heterogeneous stands. This would be a good idea even if the plot design was changed to incorporate cluster plot sampling as described below.

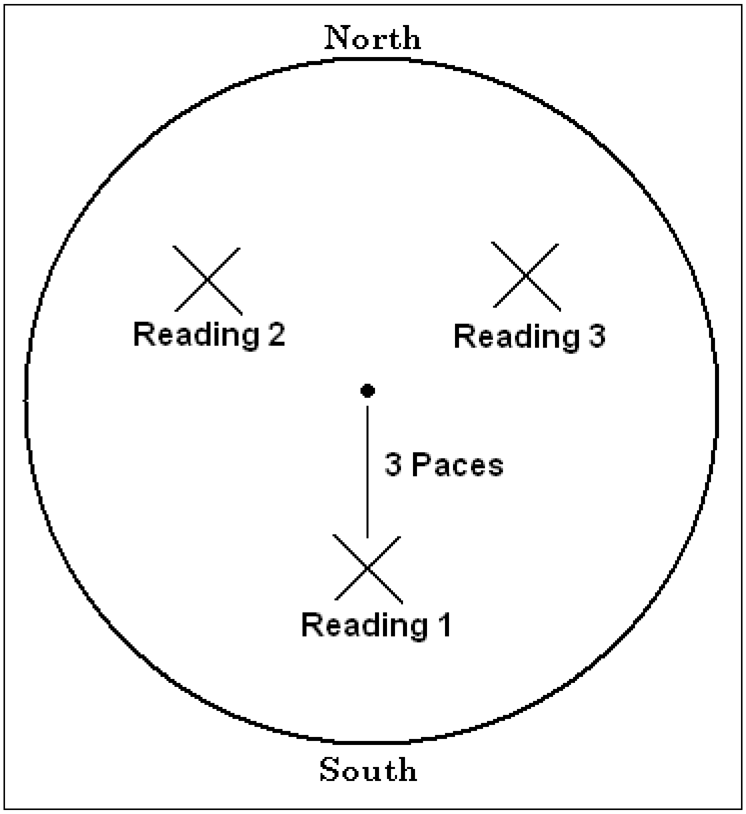

Figure 3. Example of locations for additional densiometer readings in a 0.05 acre fixed radius plot.

Small tree data

During the beginning of the October fieldwork, we recognized that small trees would not be adequately sampled with the methods described in the original RFP and laid out in our contract for the Mt. Spokane forest surveys. Since the encroachment of small, shade-tolerant tree species has been widely recognized as one of the most significant consequences of decades of fire suppression and careless forest management, it became apparent that we needed to collect some additional information on the small tree characteristics of the forest survey plots. As a result, we quickly developed protocols for gathering a minimum of information about small trees and incorporated this into a contract amendment. First, we defined small trees to be those less than 4 inches DBH. For all such trees, we counted (or estimated in the case where there where hundreds of small trees) the number of stems in each fixed radius (1/20th acre) plot. We also estimated the percent of the ground covered by small trees in the fixed radius plot. In most cases we also noted the dominant species of small trees (although this was not incorporated in our contract amendment).

The protocol for gathering small tree information described above provided the bare minimum of information that we needed for the Mt. Spokane forest health assessment. After analyzing this data and developing prescriptions for selected stands at Mt. Spokane, we recognize now that more refined data would be very useful in subsequent projects of this nature. Since the characteristics of small trees are such an important indicator of forest health conditions, it would be advantageous to expand the small tree data collection beyond what we did at Mt. Spokane.

We propose that in future projects the following information be collected on small trees:

- Stem count and cover of small trees estimated and recorded for EACH species of small tree present.
- Estimate % of small trees in three height classes, 0-3 feet, 3-10 feet and 10-40 feet (for EACH species present).

Shrub data

We recommend quickly estimating the total % shrub cover, total % grass cover, total % forb cover, total % fern cover, and total % moss cover at each fixed radius plot. The information that was collected on the three most dominant understory species was helpful, but in stands with high understory diversity, the 3 understory species information did not tell us enough and probably lead to some degree of mischaracterization of these plots. The information collected on the total number of shrub species present did not prove to be that useful.

Plant growth form decisions before surveys

We encountered some issues related to classification of certain species of plant into a growth form. First, there was the issue of classification of species which can be called either small trees or tall shrubs. Examples of these species are Douglas-maple (*Acer glabrum* var. *douglasii*) and Scouler's willow, (*Salix scouleriana*). These species are normally classified as tall shrubs, as they are relatively short compared to most trees in the Pacific Northwest and they often branch below ground level into many stems. But at some sites at Mt. Spokane, they can reach heights of 50 feet or more, which places their live foliage in the midst of the tree canopies. This makes for a difficult, data-collection dilemma. Perhaps it is best handled by putting the few species that have both shrub and tree characteristics into a special class and collect data specific to them.

One interesting aspect of this issue is that some shrub species (e.g. Douglas maple, Sitka alder, Scouler's willow) produce substantial amounts of deciduous leaf litter. This leaf litter was sufficient in some cases for the fire behavior fuel model to be a TL2 (deciduous litter) fuel model. But the stand would have been characterized as a coniferous forest stand based on the tree composition as we measured it, since the species listed above were considered shrub species in our study.

Another interesting aspect of this issue is that stands that have significant amounts of these tall shrubs extending into the forest canopy will have less flammability (in all but the driest live fuel moisture scenarios) due to the high live fuel moisture levels that are achieved in these lush shrub species. Documentation of their presence and abundance would help in determining the potential flammability of the stands. Also, knowing the amount of these species in a stand could aid in monitoring of prescriptions that are designed to increase the lush, deciduous component of a stand for fire hazard reduction purposes.

Another aspect of the shrub/small tree issue is that when species, such as Douglas maple or Scouler's willow, are tall they impact the forest canopy layering in a way that can affect bird flyways under the main canopy. Better data on this effect could effect habitat evaluations for species like the northern goshawk.

In a similar vein, our study area contained significant amounts of beargrass (*Xerophyllum tenax*). This species is most properly classified as a shrub, but is often treated either as an herb or a graminoid. In terms of fire behavior, in dry conditions, it can behave like a grass, due to its leaf structure and growth form. We treated it as a grass when evaluating fuel models. However, we listed it as a shrub in the polygon data forms.

Clarification of some of these plant growth form issues at the start of a project will be helpful, but it is important to recognize that some of the issues surrounding the classification are complex. For example, if we sampled tall shrubs as trees, they would have been sampled very rarely in the variable radius tree plots. We recommend treating them as "small trees" and including them in the small tree counts described above as the best way to handle them. They should also be recorded as shrubs on polygon forms and reconnaissance ecology plot data sheets.

Stand age data

More stand age data would be useful. We collected stand age data when time allowed, but there was not a specific requirement for collection of this data. Stand age data requires increment boring and can lengthen the survey time considerably. However, stand age data is helpful in evaluating forest health conditions. In the Mt. Spokane forest health assessment project, we collected enough representative stand age data to get an overall sense of the age classes present in the study area.

In future projects, we recommend specific requirements for collection of stand age data. With a sample intensity similar to the Mt. Spokane project, coring one of the dominant trees in every other plot would be sufficient to get a general sense of stand age. Coring a tree in each plot would be better, and coring every fifth plot would still give information about the general age distribution in relationship to stem diameter. The amount of coring possible would depend on the budget and time constraints.

Fire history data

Ideally, considerable fire scar data would be collected during the forest survey and incorporated into the data analysis. It can be very time consuming to collect good fire history data from tree scars and origin dates. Depending on budget constraints, it would be good to collect as much fire scar data by cutting fire scars out of cat-faced trees or through increment boring techniques (Morrison and Swanson 1990). The fire scar samples should be prepared (sanded and polished) and analyzed (count rings between scars and cross-date if possible). From this scar data and from tree origin dates collected from increment cores, a fire history of a project area can be constructed. The abundance of charcoal in soil and char on trees, snags and logs should also be noted and can provide information about recent fires that may not be recorded in fire scars. A comprehensive fire history for the study area that extends back into the pre-settlement time period (before 1850) can provide great insights into the long-term trends in forest condition and health. While collection of this site based information is preferable, more limited on-site data collection supplemented by good review of existing fire history literature for the local area and region (as describe in a later section of this report) may well be sufficient and adequate for most purposes.

Coarse woody debris measurements

The requirements of our contract with regard to coarse woody debris (CWD) data information were minimal and additional information could have been collected that would have greatly improved the CWD information for both wildlife and wildfire modeling. There was no size class information collected. After returning from the field, we only knew that the CWD was over 6 inches in diameter. In future projects we recommend a tally of CWD by 3 size classes and by decay class is recommended. The following size classes are recommended:

- 6-12 inches
- 12-24 inches
- over 24 inches

Fire and fuels data

When gathering fuels data, there is a trade-off on the cost of gathering more detailed data versus the ability to achieve successful results.

Data from the forest condition assessment plots was used to determine fuel loads for input into the fire behavior software programs. Because the plot data was designed from standard silvicultural surveys, important fuel characteristics had to be calculated *ad hoc* into the programs. These calculations were based on field measurements made during a follow-up visit to Mt. Spokane, when we sampled a number of plots for fuel characteristics, particularly depth of duff and litter. In future studies that potentially involve fire hazard modification, it will be important to include more quantitative measurements of fuels data using fuel inventory methods such as those in Brown (1974).

Brown (1974) describes a quantitative method for making measurements of fuel data required for fire behavior modeling. Fuel load parameters that should be determined include fuel loads for 1-hr fuels, 10-hr fuels, 100-hr fuels, 1000-hr fuels (3-9inch) 1000-hr fuels (>9-inch), herbaceous fuels, woody fuels, litter depth and duff depth.

Brown's planar intercept method for sampling fuels uses minimal equipment: 75-foot tape, compass, clear, plastic six-inch ruler, clinometer, diameter tape, survey flags, and optionally, a Go/No-Go gauge (see below). A 75-foot transect is established and several subsections along the transect are used to sample dead and down woody debris (DWD) pieces. DWD is tallied in the standard fire size classes: 1-hour (0 to 0.25 in.), 10-hour

(0.25 to 1.0 in.), 100-hour (1.0 to 3.0 in.). Pieces greater than 3 in. in diameter are recorded individually by diameter and decay class. Duff and litter depth are measured at two points along the transect and abundance of live and dead vegetation is estimated.

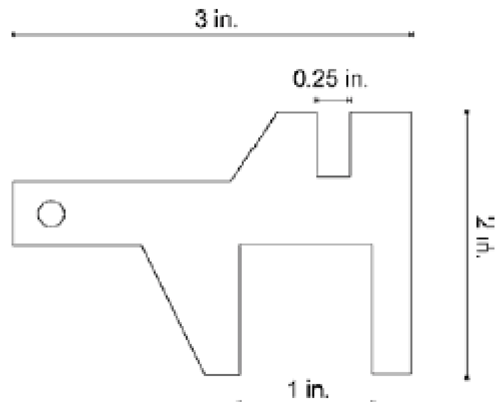

Figure XX. A Go/No Guage for estimating fuel class (illustration from p. FL-6, Final Draft, Fuel Load (FL) Sampling Method; In: Duncan Lutes, *Fire Effects Monitoring and Inventory Protocol: Sampling Methods*, Systems for Environmental Management, Missoula, Montana; online at http://frames.nbii.gov/firemon/).

In the full method cited by Brown, 3 transects are established per stand, and additional transects are sampled, until 100 pieces of fuel have been tallied. In fuel sampling studies made by George Wooten for the Department of Wildlife, it was possible to modify Brown's method by using only a single well-placed transect, and by skipping it entirely in open or rocky stands that did not need quantitative fuel measurements. This made it possible to measure fuel loads on about 20 plots a day, when the plots were readily accessible. Fuel sampling can also be expedited by making the fuel measurements conform with other silvicultural measurements, e.g., for down logs, shrubs and herbs.

Photo series for determining fuel loads, e.g., Fischer (1981), are another useful and rapid way to assess fuel loads. If they are not available for a given study area, a library of photos can be created in-house during the fuel inventories.

A new method of estimating surface fuel loadings has recently been developed based on a sampling method called "photoload sampling" (Keane and Dickinson 2007a, 2007b). This technique can supposedly be used to quickly and accurately estimate loadings for six common surface fuel components (1 hr, 10 hr, 100 hr, 1000 hr downed dead woody, shrub and herbaceous fuels). This new technique has just been published and we have not had time to evaluate it. It should be explored further for use in projects similar to the Mt. Spokane project.

Ideally, it would be good to explore the use of the Fuel Characteristics Classification System (FCCS) in future projects of this nature. We recommend incorporation of at least some of the FCCS fuel parameters, especially good information on ladder fuels, solid woody fuel data and litter data.

Fire behavior fuel models

The 40 fuel models developed by Scott and Burgan (2005) are an improvement over the original 13 fuel models, but there are still some serious inadequacies to consider. Some of these issues are briefly described in our report on the Mt. Spokane project (Morrison et al. 2007). Most importantly, the key provided by Scott and Burgan is not a strict dichotomous key, it contains gaps where no fire behavior fuel model is indicated and application of the key by various users can lead to differing interpretations of what fuel model would apply to a given situation.

In future projects we recommend development of a key to the fuel models of a project area that is specific to the fuel models found in that area. The fuel models key developed by Scott and Burgan has many problems and is not adequate for actually keying out specific fuel models. A new key should provide consistency and documentation for the fuel models chosen to represent forest survey plots. Although this might, at first glance, seem like a difficult task, it would not be difficult to accomplish by an experienced forest ecologist or fire specialist. The new key would be based on the Scott and Burgan models, but would be restricted to the particular project site. The key that Scott and Burgan provided should be modified so that it is a strictly dichotomous key that will lead the user to specific fire behavior fuel models that appropriately describe the fuel conditions at a given location.

More development work and refinement of fire behavior fuel models is needed. This comment is related to the above discussion. The reader should remember that the term “fire behavior fuel model” is a term that applies to a given fuel condition at a particular site that can be used to “model” how fire will behave at that particular site. That term does not describe a method or software suite to be used for the process of fire behavior modeling. Perhaps the FCCS system will evolve to eventually replace the current fuel model system. This work, however, is beyond the scope of what either Washington State Parks or PBI can undertake.

Sampling Design and Forest Surveys in Parks Where Vegetation Assessments Have Been Conducted

Where previous ecological and botanical studies have been done in state parks, this data can be very useful in planning future forest health studies, and can at least negate the need for the reconnaissance ecology surveys discussed above. Stand mapping can use the plant community mapping completed by previous studies as a starting point. Some modification of polygon boundaries may be necessary to meet the needs of a forest health assessment. The vegetation data collected in previous studies may also negate the need for the collection of polygon data such as that collected in Mt. Spokane project.

Also, previous ecological surveys would be very useful in defining vegetation strata and sample sizes to be used in stratified random sampling design.

The plant lists compiled from previous botanical surveys will be very useful to field crews conducting forest health surveys and should be provided at the onset of a project.

Fire History and Fire Behavior Modeling

The original SOW for the Mt. Spokane project did not call for compilation of existing data and research literature on fire ecology, fire history, and fire occurrences in the project area and vicinity. A contract amendment was added to the original SOW of the Mt. Spokane project that allowed us to compile a limited amount of information on these topics. Future projects of this nature would benefit from compiling and assessing this information toward the beginning of the project, perhaps even before fieldwork commenced, and building this information into the project in a more central fashion rather than as an afterthought.

Once again, it is important for the reader not to confuse the term "fire behavior fuel model" as applied by Scott and Burgan (2005) with the more general term "fire behavior modeling". The first term was coined by fire specialists to describe the fuel conditions at a specific location in a way that they could be used to "model" fire behavior at that site. The second term is used in a more generic sense to describe the process of modeling fire behavior at both a site and landscape scale. It implies a method, and perhaps a suite of fire behavior modeling software, that can be used to predict fire behavior. We acknowledge that these terms are very similar and confusing, but they are in widespread use in fire science and we have just adopted the use of these commonly used terms in our reports.

The original SOW for the Mt. Spokane project did not include any mention of spatial wildfire modeling. Spatial wildfire modeling using software such as FlamMap and FARSITE are considered to be essential to state-of-the-art in projects such as the Mt. Spokane project. A contract amendment was added to the original SOW of the Mt. Spokane project that allowed us to do a limited amount of spatial wildfire modeling. Future projects of this nature would benefit from building spatial wildfire modeling into the forest health assessment and forest plan development in a more central fashion rather than as an afterthought.

Wildlife Habitat Modeling

The wildlife species to be considered in a forest health assessment should be decided upon before field surveys begin. The RFP might be written to require that the contractor be responsible for literature search and contacting WDFW about potential or known occurrences of wildlife, or better, this can be done in advance by Washington State Park Staff. Washington State Parks and Department of Wildlife should provide all known data and information they possess ahead of time. A list of species to be considered or modeled should be agreed upon prior to surveys and survey protocols should be adapted to meet the needs of modeling for target species. This process is more time consuming than what was specified in the original Mt. Spokane contract, but this will provide the contractor with more information on what Parks actually wants done, and the amount of time to budget for it.

Also, specifying an HSI modeling approach for evaluating wildlife habitat may not be ideal in many park settings. The HSI modeling protocols are typically applied to landscapes and spatial regions much larger than the typical State Park setting. We were able to adapt HSI procedures to the finer scale project area landscape in Mt Spokane, but our methods had to be adapted beyond what is called for in the typical HSI modeling scheme. It may be advisable to approach habitat assessment language in the scope of work in a more general way that gives the contractor and other wildlife experts like WDFW more room to create unique protocols that better fit the sampling structure of the forest inventory and the smaller spatial scales of the park landscapes.

Another important consideration for the wildlife habitat modeling is whether or not to focus on the surrounding landscapes of the park or project area. Wildlife use and presence will always be greatly influenced by surrounding conditions of the matrix landscape, and most parks are not large enough to contain substantial areas of core habitat in which species do not migrate outside of the park boundaries. Conceptually, modeling for and creating an understanding of the habitat conditions outside of the park is important in understanding habitat use potential in the park, but this is not an easy task. Depending on the species being considered, it may be difficult to decide just how far outside the park one should be focusing on to adequately assess conditions. Also, it is likely that field surveys will not occur outside of the park's jurisdiction, so remote sensing and/or other types of data would need to be relied upon to assess non-park conditions. Assessing the conditions of non-park landscapes would add considerable costs and complexity to this type of project. It would be advisable to consider modeling landscapes outside of the park when it can be done with reasonable cost increases and complications. Such increases will vary from landscape to landscape and from species to species.

Incorporation of Information on Park Infrastructure in Forest Plan Development

Park infrastructure (e.g. roads, buildings, utility lines) are a very important component of forest planning. It is very important to consider park infrastructure when designing a plan to reduce wildfire hazards. We recommend that future SOW documents incorporate a requirement to obtain or acquire comprehensive information of park infrastructure and incorporate this information in the forest plan development. Ideally, this should be done early in the project.

Obtain and analyze a chronosequence of aerial photography and satellite imagery

Analysis of a chronosequence of aerial photography and satellite imagery can yield surprising insights into the past management activities, disturbance events and trends in forest succession. These insights can be very useful in assessing forest health and determining the best management practices for the future. Often aerial imagery is one of the few sources of information for assessing disturbance and management history of forest landscapes. Incorporation of a requirement to obtain a long chronosequence of imagery and analyze this imagery would enhance forest health assessment projects similar to the Mt. Spokane project.

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Appendix A – Variable Correlations Table

		CAN HT	CBH	CBD By Tree	CBD by Plot Regr	QTR GR4	QSN GR6	SHAN SPEC	SHAN DBH	SDI	UND MNHT	HGR Per Cov	Shrb Per Cov	Shrub DIV	CWD COV	CWD Per Acre	Total BA ACRE	CAN COV	TPAd bhcls gr4	SnPer Acre	SMTR COV	SmTr Per Acre	MAXD BH
CANHT	Pearson Correlation	1.000	.393	-.094	-.047	.583	.253	.203	.395	.240	-.074	-.069	-.156	-.171	.182	.258	.363	.306	-.162	.013	-.301	-.161	.605
	Sig. (2-tailed)	.	.000	.058	.346	.000	.000	.000	.000	.000	.137	.166	.002	.001	.000	.000	.000	.000	.001	.788	.000	.001	.000
	N	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406
CBH	Pearson Correlation	.393	1.000	.115	.136	.225	.106	.273	.306	.370	-.196	.040	-.143	-.167	.224	.287	.399	.164	.051	.223	-.236	-.162	.230
	Sig. (2-tailed)	.000	.	.020	.006	.000	.032	.000	.000	.000	.000	.416	.004	.001	.000	.000	.000	.001	.306	.000	.000	.001	.000
	N	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406
CBDby Tree	Pearson Correlation	-.094	.115	1.000	.885	-.403	-.096	-.009	.246	.806	-.228	.033	-.370	-.326	-.049	.016	.709	.423	.834	.152	-.119	-.197	.117
	Sig. (2-tailed)	.058	.020	.	.000	.000	.052	.864	.000	.000	.000	.503	.000	.000	.320	.752	.000	.000	.000	.002	.016	.000	.018
	N	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406
CBDbyPlotRegr	Pearson Correlation	-.047	.136	.885	1.000	-.503	-.118	.031	.195	.835	-.186	-.045	-.338	-.231	-.016	.023	.702	.409	.968	.184	-.107	-.173	.061
	Sig. (2-tailed)	.346	.006	.000	.	.000	.018	.530	.000	.000	.000	.361	.000	.000	.754	.645	.000	.000	.000	.000	.031	.000	.222
	N	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406
QTRGR4	Pearson Correlation	.583	.225	-.403	-.503	1.000	.226	.177	.279	-.115	-.030	.071	.057	-.086	-.005	.025	.075	.016	-.623	-.068	-.256	-.114	.472
	Sig. (2-tailed)	.000	.000	.000	.000	.	.000	.000	.000	.020	.551	.154	.250	.084	.917	.619	.133	.747	.000	.170	.000	.022	.000
	N	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406
QSNGR6	Pearson Correlation	.253	.106	-.096	-.118	.226	1.000	.054	.102	-.021	-.052	-.062	.019	-.032	.220	.235	.030	.018	-.143	.153	-.030	-.034	.244
	Sig. (2-tailed)	.000	.032	.052	.018	.000	.	.273	.039	.666	.292	.210	.702	.518	.000	.000	.548	.713	.004	.002	.548	.498	.000
	N	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406
SHANSPEC	Pearson Correlation	.203	.273	-.009	.031	.177	.054	1.000	.331	.175	-.173	.044	-.083	-.022	.046	.091	.216	.129	-.029	.051	-.091	-.007	.283
	Sig. (2-tailed)	.000	.000	.864	.530	.000	.273	.	.000	.000	.000	.381	.096	.657	.357	.066	.000	.009	.567	.303	.068	.889	.000
	N	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406
SHANDBH	Pearson Correlation	.395	.306	.246	.195	.279	.102	.331	1.000	.484	-.219	.034	-.212	-.257	.032	.108	.562	.317	.064	.016	-.279	-.205	.588
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.039	.000	.	.000	.000	.489	.000	.000	.515	.030	.000	.000	.197	.743	.000	.000	.000
	N	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406

		CAN HT	CBH	CBD By Tree	CBD by Plot Regr	QTR GR4	QSN GR6	SHAN SPEC	SHAN DBH	SDI	UND MNHT	HGR Per Cov	Shrb Per Cov	Shrub DIV	CWD COV	CWD Per Acre	Total BA ACRE	CAN COV	TPAd bhcls gr4	SnPer Acre	SMTR COV	SmTr Per Acre	MAXD BH
SDI	Pearson Correlation	.240	.370	.806	.835	-.115	-.021	.175	.484	1.000	-.300	.018	-.407	-.388	.014	.101	.970	.503	.698	.184	-.321	-.305	.380
	Sig. (2-tailed)	.000	.000	.000	.000	.020	.666	.000	.000	.	.000	.715	.000	.000	.780	.043	.000	.000	.000	.000	.000	.000	.000
	N	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406
UNDMNHT	Pearson Correlation	-.074	-.196	-.228	-.186	-.030	-.052	-.173	-.219	-.300	1.000	-.233	.265	.190	-.205	-.228	-.301	-.011	-.118	-.209	.175	.070	-.144
	Sig. (2-tailed)	.137	.000	.000	.000	.551	.292	.000	.000	.000	.	.000	.000	.000	.000	.000	.000	.825	.018	.000	.000	.156	.004
	N	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406
HGRPerCov	Pearson Correlation	-.069	.040	.033	-.045	.071	-.062	.044	.034	.018	-.233	1.000	-.070	-.235	-.014	-.014	.034	-.113	-.064	.080	-.125	-.042	.011
	Sig. (2-tailed)	.166	.416	.503	.361	.154	.210	.381	.489	.715	.000	.	.156	.000	.777	.775	.492	.023	.202	.108	.011	.398	.821
	N	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406
ShrbPerCov	Pearson Correlation	-.156	-.143	-.370	-.338	.057	.019	-.083	-.212	-.407	.265	-.070	1.000	.398	-.096	-.141	-.412	-.336	-.285	-.058	.010	.061	-.169
	Sig. (2-tailed)	.002	.004	.000	.000	.250	.702	.096	.000	.000	.000	.156	.	.000	.053	.004	.000	.000	.000	.240	.835	.217	.001
	N	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406
SHRUBDIV	Pearson Correlation	-.171	-.167	-.326	-.231	-.086	-.032	-.022	-.257	-.388	.190	-.235	.398	1.000	-.028	-.101	-.420	-.276	-.155	-.119	.310	.303	-.215
	Sig. (2-tailed)	.001	.001	.000	.000	.084	.518	.657	.000	.000	.000	.000	.000	.	.569	.041	.000	.000	.002	.017	.000	.000	.000
	N	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406
CWDCov	Pearson Correlation	.182	.224	-.049	-.016	-.005	.220	.046	.032	.014	-.205	-.014	-.096	-.028	1.000	.796	.018	-.029	-.033	.240	.044	.113	.028
	Sig. (2-tailed)	.000	.000	.320	.754	.917	.000	.357	.515	.780	.000	.777	.053	.569	.	.000	.720	.558	.506	.000	.381	.023	.574
	N	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406
CWDPerAcre	Pearson Correlation	.258	.287	.016	.023	.025	.235	.091	.108	.101	-.228	-.014	-.141	-.101	.796	1.000	.112	.048	-.010	.275	-.056	.065	.114
	Sig. (2-tailed)	.000	.000	.752	.645	.619	.000	.066	.030	.043	.000	.775	.004	.041	.000	.	.024	.338	.847	.000	.258	.191	.021
	N	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406
TotalBAACRE	Pearson Correlation	.363	.399	.709	.702	.075	.030	.216	.562	.970	-.301	.034	-.412	-.420	.018	.112	1.000	.507	.533	.140	-.378	-.333	.521
	Sig. (2-tailed)	.000	.000	.000	.000	.133	.548	.000	.000	.000	.000	.492	.000	.000	.720	.024	.	.000	.000	.005	.000	.000	.000
	N	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406
CANCov	Pearson Correlation	.306	.164	.423	.409	.016	.018	.129	.317	.503	-.011	-.113	-.336	-.276	-.029	.048	.507	1.000	.365	.047	-.080	-.115	.315
	Sig. (2-tailed)	.000	.001	.000	.000	.747	.713	.009	.000	.000	.825	.023	.000	.000	.558	.338	.000	.	.000	.346	.107	.020	.000
	N	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406

		CAN HT	CBH	CBD By Tree	CBD by Plot Regr	QTR GR4	QSN GR6	SHAN SPEC	SHAN DBH	SDI	UND MNHT	HGR Per Cov	Shrb Per Cov	Shrub DIV	CWD COV	CWD Per Acre	Total BA ACRE	CAN COV	TPAd bhcls gr4	SnPer Acre	SMTR COV	SmTr Per Acre	MAXD BH
TPAdbhclsgr4	Pearson Correlation	-.162	.051	.834	.968	-.623	-.143	-.029	.064	.698	-.118	-.064	-.285	-.155	-.033	-.010	.533	.365	1.000	.179	.009	-.089	-.072
	Sig. (2-tailed)	.001	.306	.000	.000	.000	.004	.567	.197	.000	.018	.202	.000	.002	.506	.847	.000	.000	.	.000	.852	.074	.147
	N	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406
SnPerAcre	Pearson Correlation	.013	.223	.152	.184	-.068	.153	.051	.016	.184	-.209	.080	-.058	-.119	.240	.275	.140	.047	.179	1.000	-.023	-.018	-.064
	Sig. (2-tailed)	.788	.000	.002	.000	.170	.002	.303	.743	.000	.000	.108	.240	.017	.000	.000	.005	.346	.000	.	.642	.723	.201
	N	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406
SMTRCOV	Pearson Correlation	-.301	-.236	-.119	-.107	-.256	-.030	-.091	-.279	-.321	.175	-.125	.010	.310	.044	-.056	-.378	-.080	.009	-.023	1.000	.690	-.336
	Sig. (2-tailed)	.000	.000	.016	.031	.000	.548	.068	.000	.000	.000	.011	.835	.000	.381	.258	.000	.107	.852	.642	.	.000	.000
	N	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406
SmTrPerAcre	Pearson Correlation	-.161	-.162	-.197	-.173	-.114	-.034	-.007	-.205	-.305	.070	-.042	.061	.303	.113	.065	-.333	-.115	-.089	-.018	.690	1.000	-.233
	Sig. (2-tailed)	.001	.001	.000	.000	.022	.498	.889	.000	.000	.156	.398	.217	.000	.023	.191	.000	.020	.074	.723	.000	.	.000
	N	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406
MAXDBH	Pearson Correlation	.605	.230	.117	.061	.472	.244	.283	.588	.380	-.144	.011	-.169	-.215	.028	.114	.521	.315	-.072	-.064	-.336	-.233	1.000
	Sig. (2-tailed)	.000	.000	.018	.222	.000	.000	.000	.000	.000	.004	.821	.001	.000	.574	.021	.000	.000	.147	.201	.000	.000	.
	N	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406	406

Correlation is significant at the 0.01 level (2-tailed).
Correlation is significant at the 0.05 level (2-tailed).

VARIABLES

CANHT – Canopy Height

CBH – Canopy Base Height
CBDbyTree – Canopy Bulk Density, calculated on per-tree basis and summed for plot
CBDbyPlotRegr – Canopy Bulk Density, calculated using a regression formula for the plot as whole
QTRGR4 – Quadratic Mean Diameter of trees greater than 4" dbh.
QSNGR6 – Quadratic Mean Diameter of snags greater than 6" dbh
SHANSPEC – Shannon's Diversity index of tree species
SHANDBH – Shannon's Diversity Index of tree dbh's
SDI – Stand Density Index
UNDMNHT – Understory mean height
HGRPERCOV – Percent cover of herbs & grasses
SHRBPERCOV – Percent cover of shrubs
SHRUBDIV – Shrub diversity
CWDCOV – Coarse Woody debris percent cover
CWDPERACRE – Coarse Woody debris per acre
TPAdbhclsgr4 – Trees per acre of dbh greater than 4"
SnPerAcre – Snags per acre
SMTRCOV – Percent cover of small trees
SmTrPerAcre – Small trees per acre
MAXDBH – Maximum dbh

Appendix B - Plot Resample Analysis

The goal of this analysis was to assess whether less plots in polygons that appeared to have relatively uniform forest characteristics would still provide reasonable estimates for particular variables. We chose to assess the impact of the number of plots per polygon on the following variables, which describe the most important stand attributes for the purpose of forest health assessment: 1) quadratic mean diameter, 2) percent slope, 3) aspect, 4) density of coarse woody debris, 5) percent cover of coarse woody debris, 6) snag density, 7) total trees/acre, 8) diversity of tree species, 9) percent cover of shrubs, 10) percent cover of herbs and grasses, 11) canopy cover, 12) basal area/acre, 13) small tree density, 14) canopy bulk density, 15) canopy base height, and 16) fuel bed depth.

A resampling analysis was conducted on each of 3 polygons, which appeared to be relatively uniform in terms of stand characteristics – polygons #1, #21, and #25. These polygons contained 12, 7, and 14 plots, respectively. For each polygon, random sub-samples were drawn, ranging in size from 1 plot/polygon up to the maximum number of plots in that polygon. This was repeated 1000 times for each subsample size for each polygon, then the mean of the variables was calculated for each of the 1000 replicates. Variances of the subsample means were also calculated.

An example of the resampling results is shown below, using polygon #25 with the variable Canopy Bulk Density (CBD). Figure 1 shows the mean CBD values for each subsample, according to sample size (i.e. number of plots per polygon). For each sample size along the x-axis, 1000 mean CBD values are graphed.

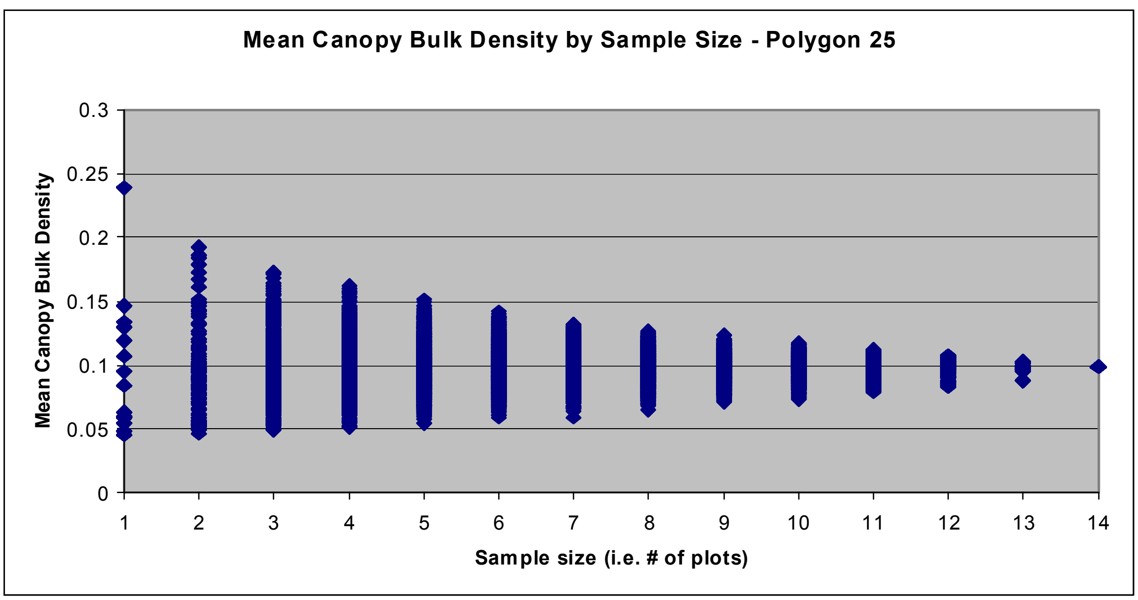


Figure 1. Graph of mean Canopy Bulk Density values from resampling analysis.

Box plots (Figure 2), which more clearly represent the data distributions and how they are affected by sample size, were graphed for each variable for each polygon. The x-axis represents the number of plots or subsample size, ranging from 1 to 14 (because polygon #25 contains 14 plots). The box above each sample size shows where the middle 50% of the mean values (of the 1000 subsamples for that sample size) are contained. The bar in the box represents the median value. The bottom bar (below the box) is the lower 25% of mean values, and the upper bar is the upper 25% of mean values. Outliers are not shown. The graph shows that the variation of potential mean values decreases as sample size increases, and there is notably less variation in mean CBD values in subsamples containing approximately 7 or more plots, than in subsamples with fewer plots.

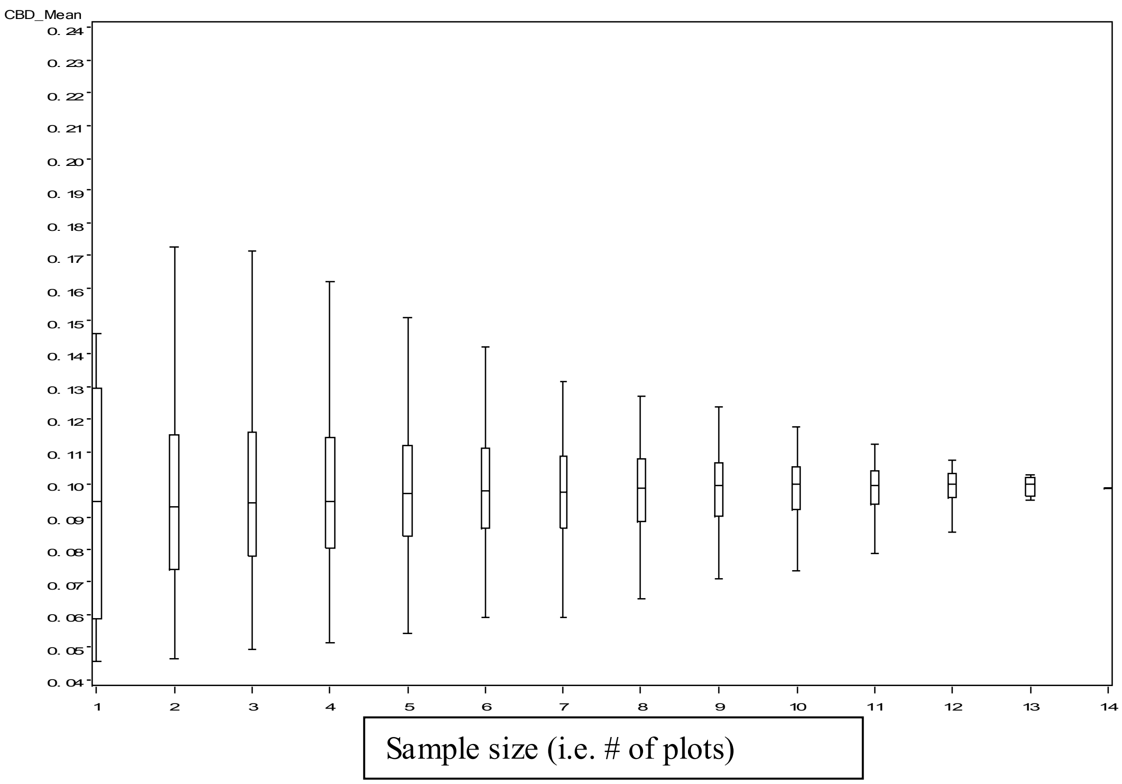
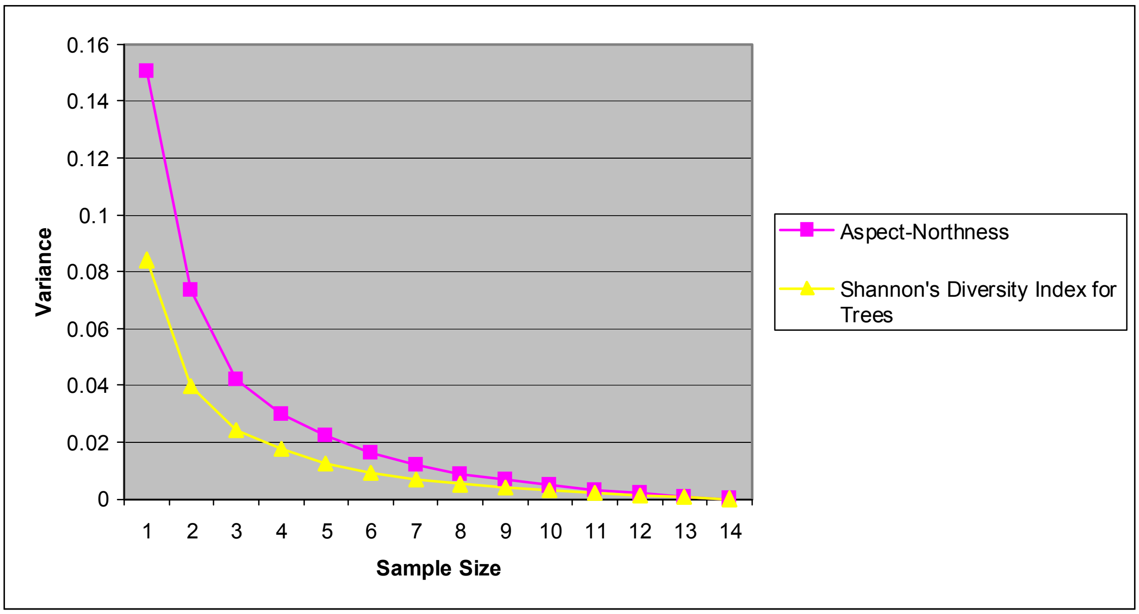
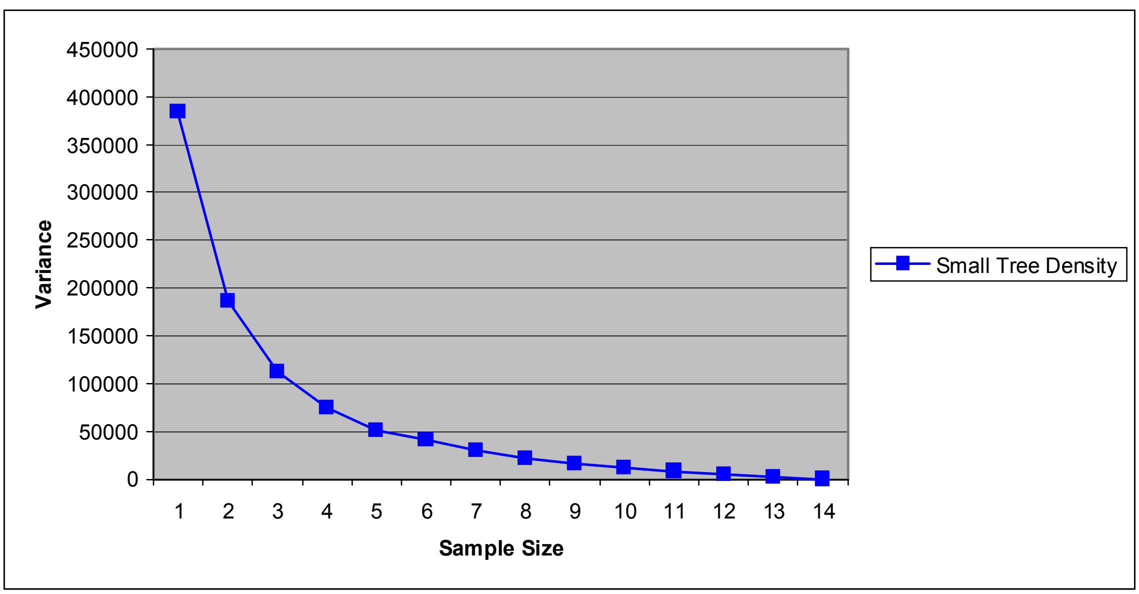


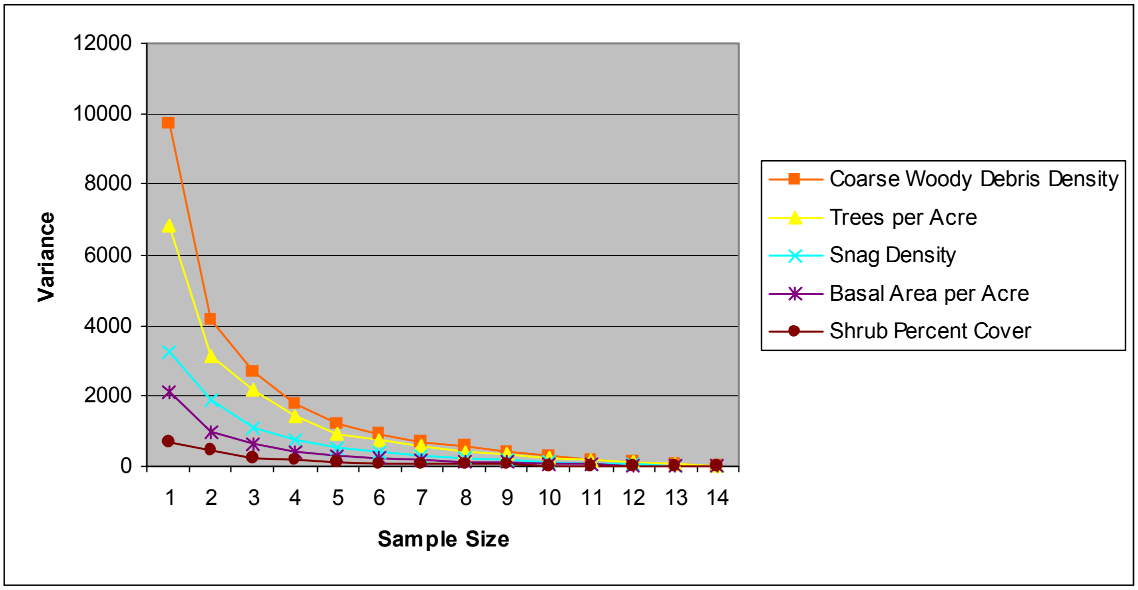
Figure 2. Mean canopy bulk density values according to sample size (i.e. number of plots) for polygon #25.

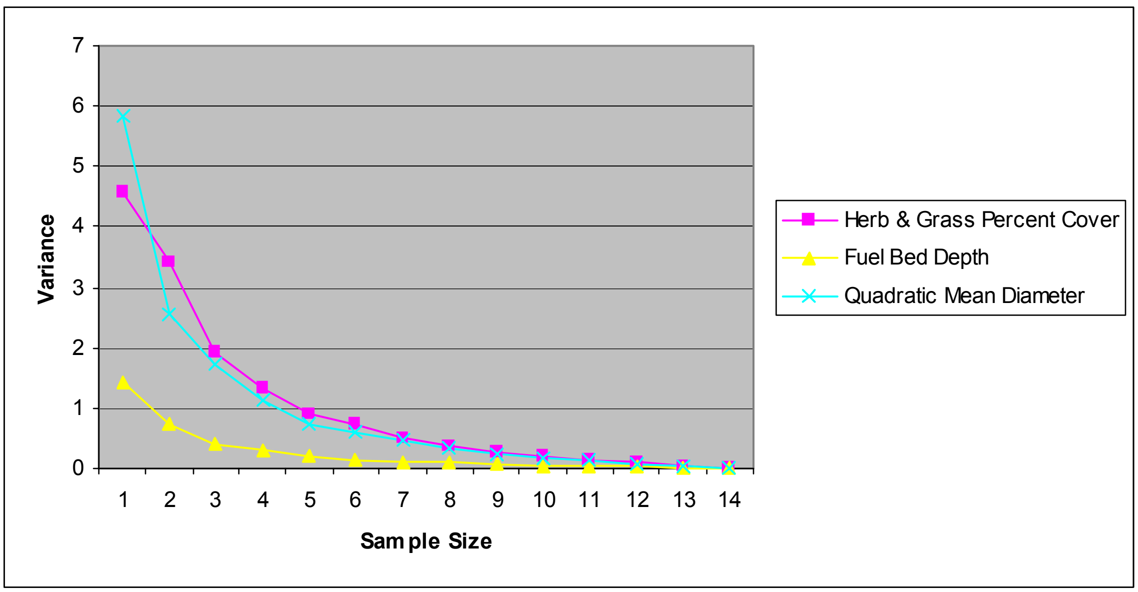
We looked at the box plots for each of the 3 polygons, for each variable. Trends appeared similar in the 3 polygons. For example, if the variation of potential mean values for a particular variable was noticeably less in sample sizes of 5 or greater in one of the polygons, this commonly appeared to be true for the other 2 polygons as well. For most of the variables, the box plots showed a notable decrease in variation of potential mean values somewhere in the range of 5 to 7 plots per polygon.

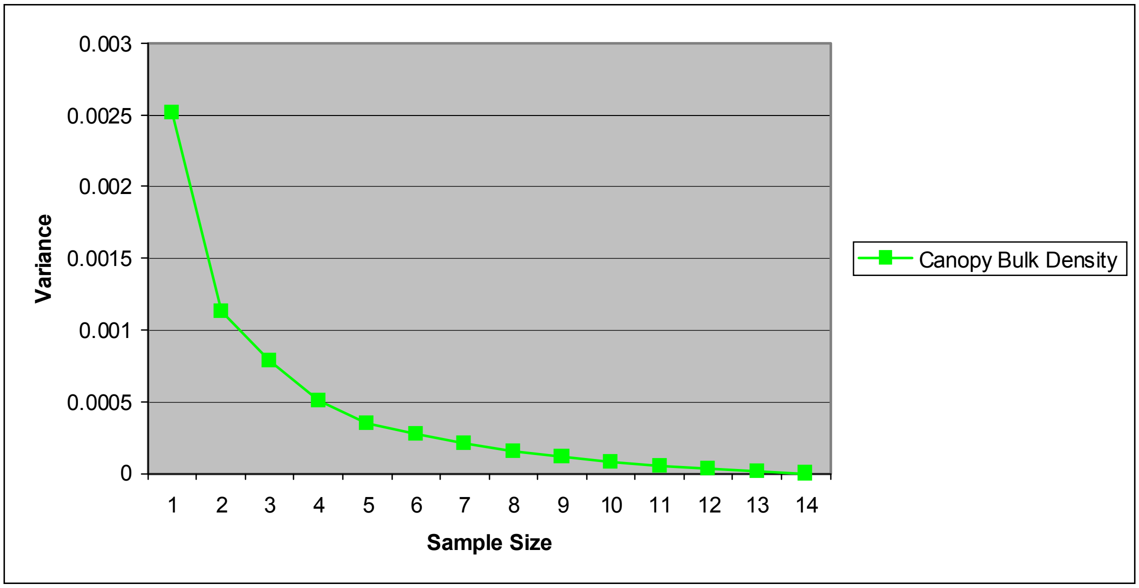
As another way of viewing the effect of plot numbers on the variables, we graphed the variance of the subsample means, according to sample size. These graphs are shown below for polygon #25 (Figure 3, a-f). Variables are grouped on different graphs according to the scale of their variance values (y-axis). These graphs also clearly show that there is notably less variation in all variables with sample sizes of 5 plots or greater, and that by 7 or 8 plots, the amount of variation decreased with increased sampling is negligible.






12000
10000
8000
6000
4000
2000
0
Variance
1 2 3 4 5 6 7 8 9 10 11 12 13 14
Sample Size
Coarse Woody Debris Density
Trees per Acre
Snag Density
Basal Area per Acre
Shrub Percent Cover


7
6
5
4
3
2
1
0
Variance
1 2 3 4 5 6 7 8 9 10 11 12 13 14
Sample Size
Herb & Grass Percent Cover
Fuel Bed Depth
Quadratic Mean Diameter



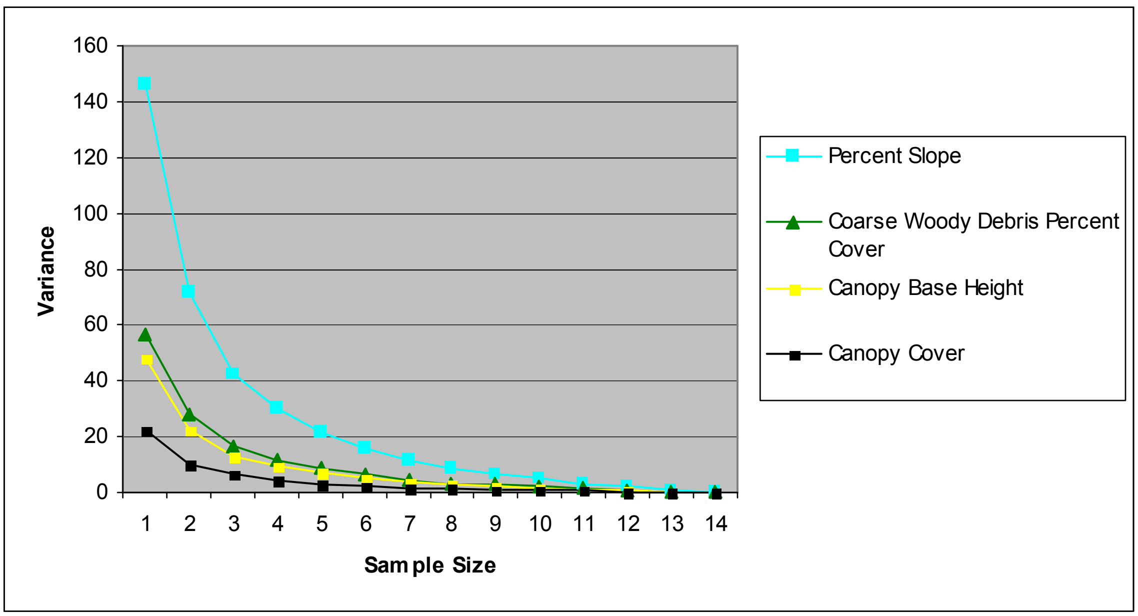
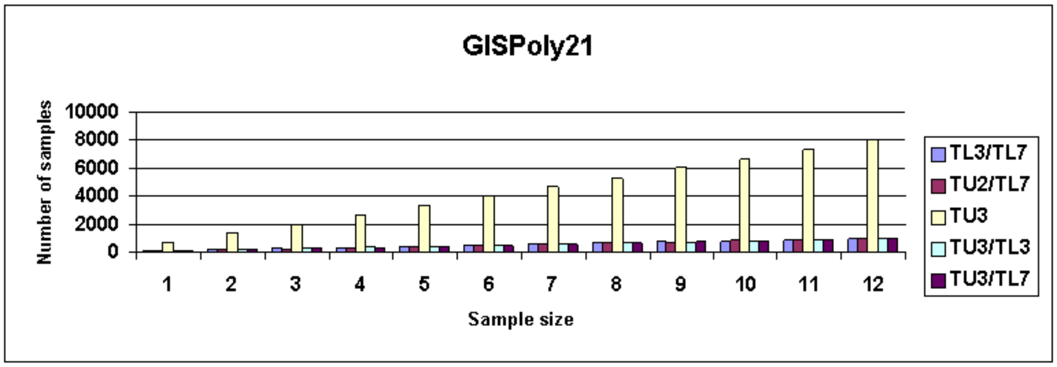
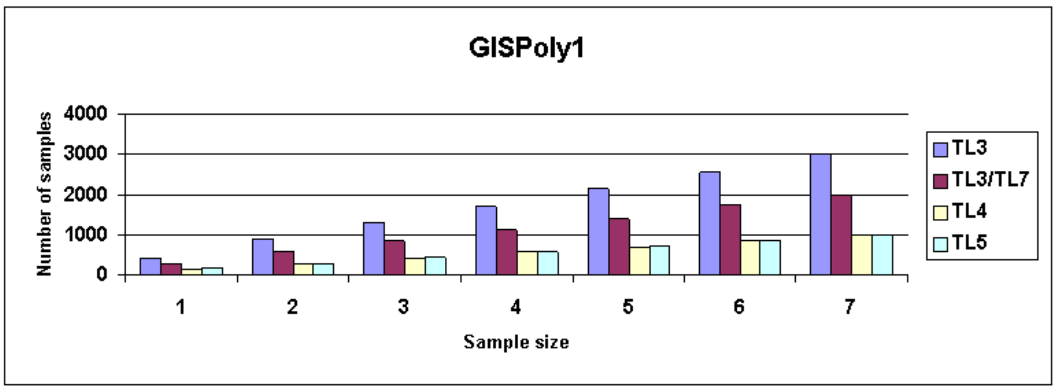


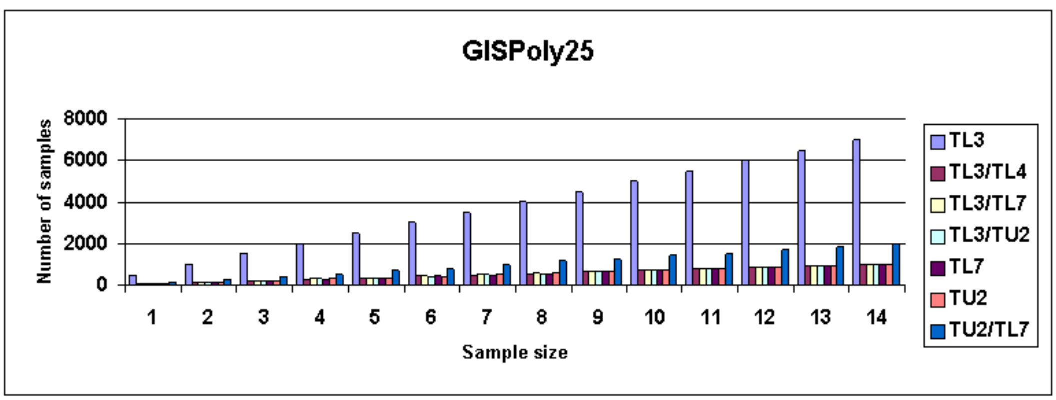
Figure 3 (a-f). Six graphs showing effect of sample size (i.e. number of plots/polygon) on the variance of mean values of Plot 25 variables.

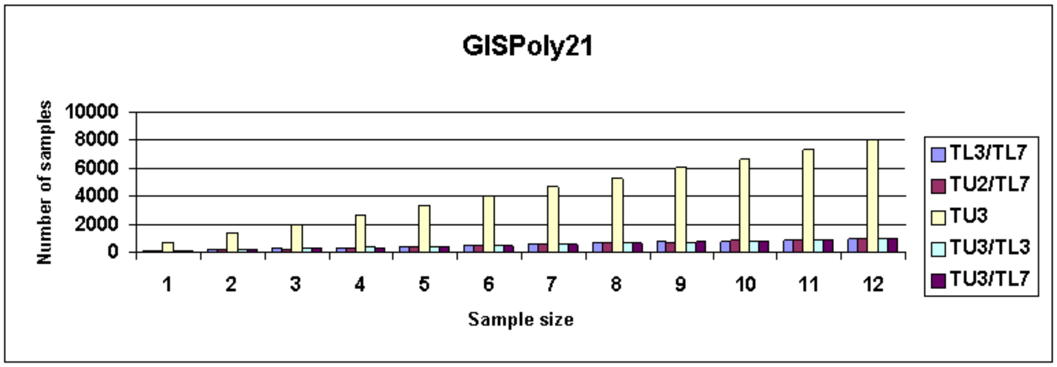
Resample Analysis for Fuel Model

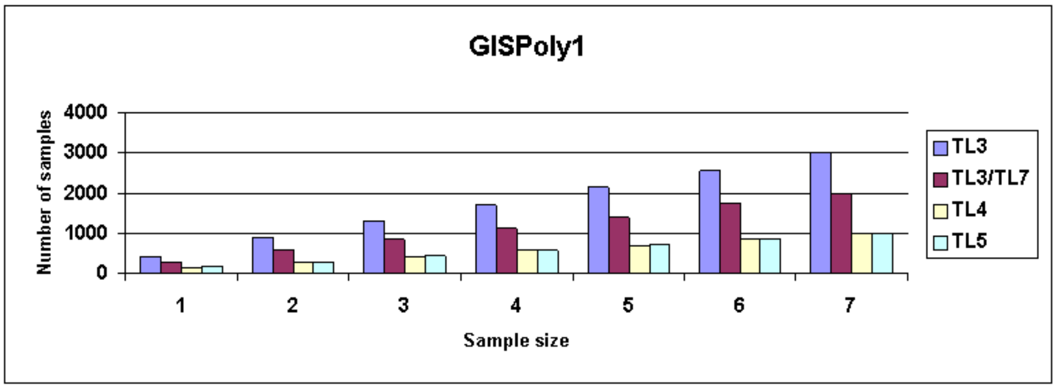
The following graphs show the number of times a plot with a given fuel model is randomly drawn (y-axis) when the total number of plots drawn (i.e. sample size - x-axis) for a polygon range from 1 to the maximum number of plots within that polygon.

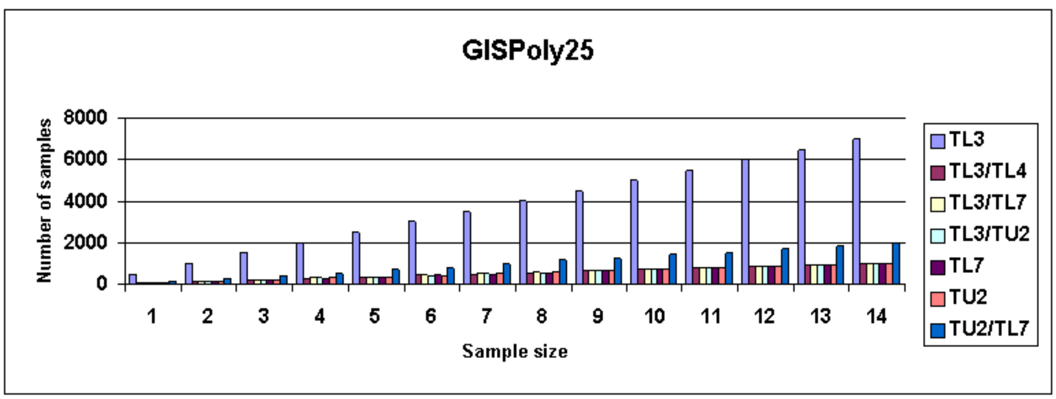






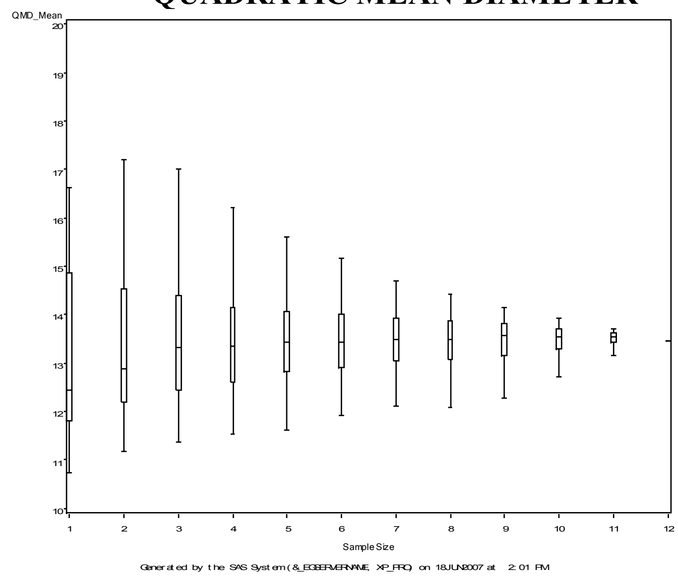

GISPoly21
Number of samples
10000
8000
6000
4000
2000
0
1
2
3
4
5
6
7
8
9
10
11
12
Sample size
TL3/TL7
TU2/TL7
TU3
TU3/TL3
TU3/TL7


GISPoly1
Number of samples
4000
3000
2000
1000
0
1
2
3
4
5
6
7
Sample size
TL3
TL3/TL7
TL4
TL5

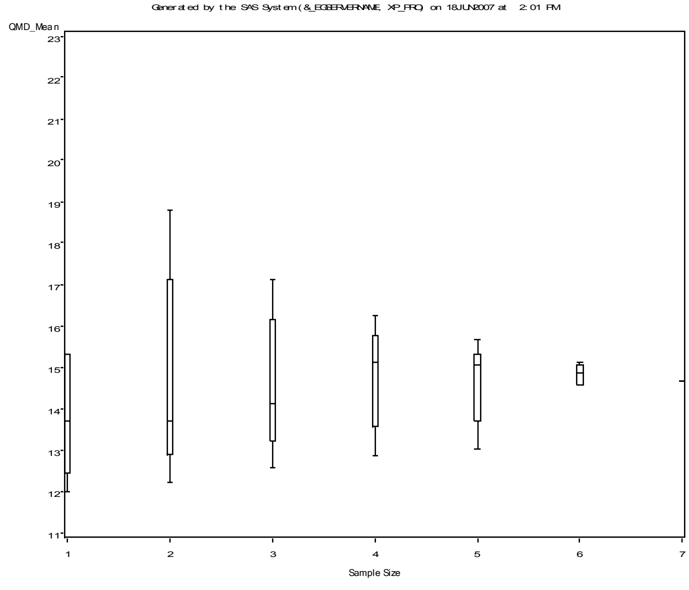

GISPoly25
Number of samples
8000
6000
4000
2000
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Sample size
TL3
TL3/TL4
TL3/TL7
TL3/TU2
TL7
TU2
TU2/TL7

Box Plots for Forest Condition Variables

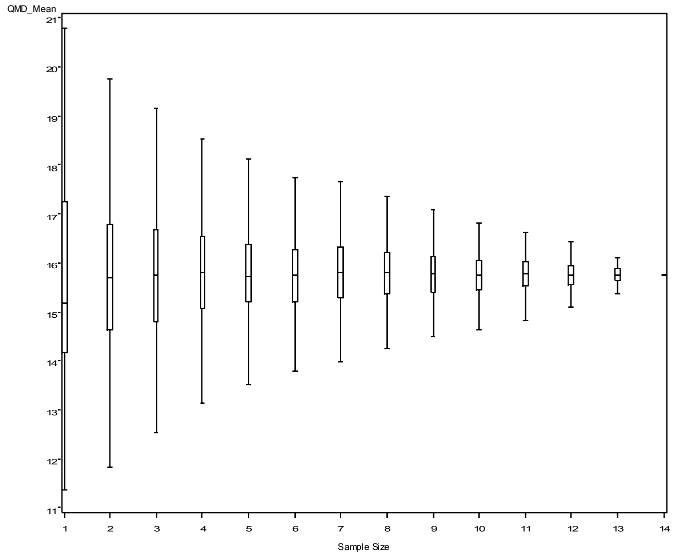
QUADRATIC MEAN DIAMETER



POLY1



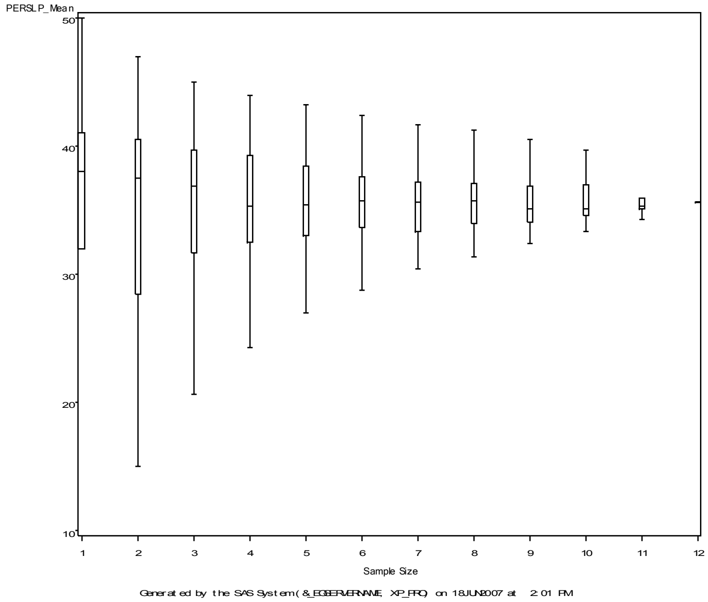
POLY21



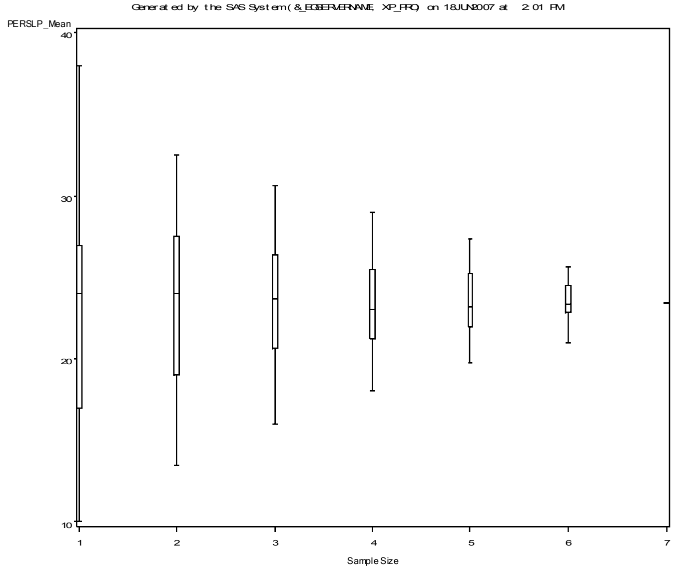
Generated by the SAS System (&_EGSERVERNAME, XP_PRO) on 18JUN2007 at 2:16 PM

POLY25

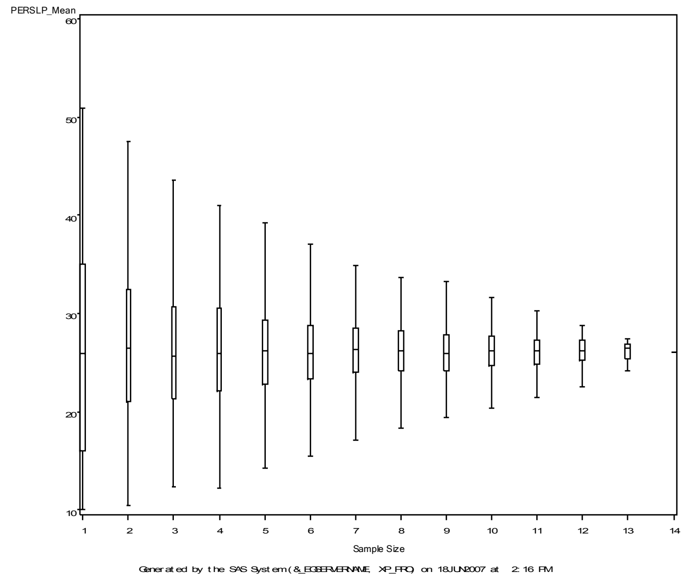
PERCENT SLOPE



POLY1

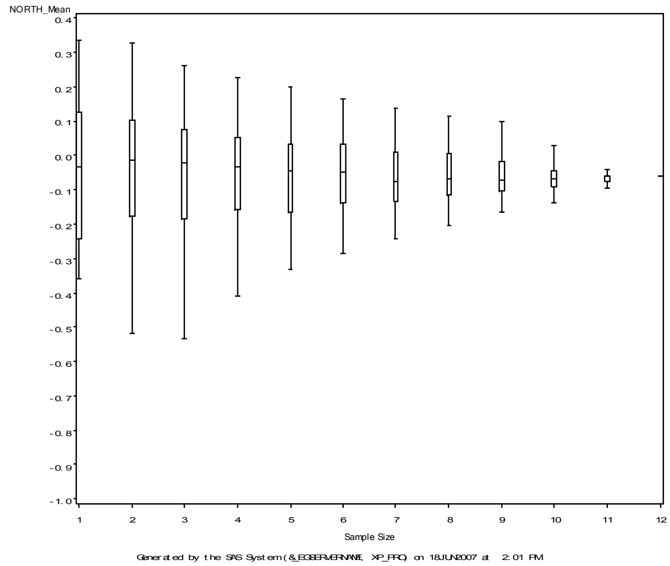


POLY21

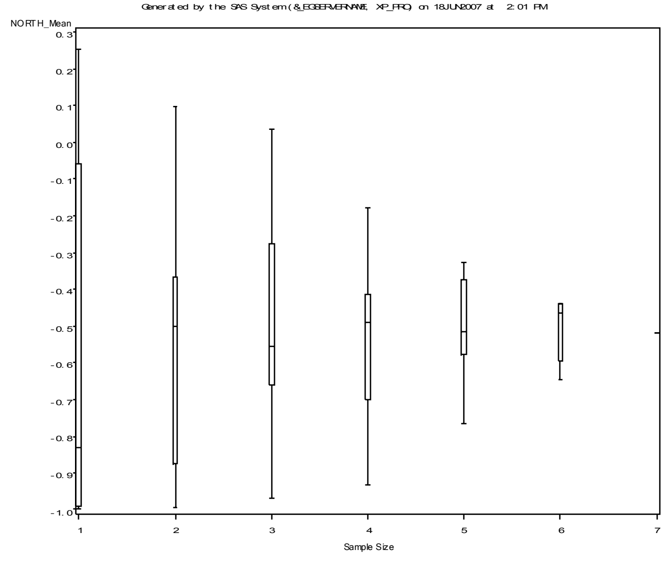

PERSLP_Mean
60
50
40
30
20
10
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Sample Size
Generated by the SAS System (&_EGSERVERNAME, XP_PRO) on 18JUN2007 at 2:16 PM

POLY25

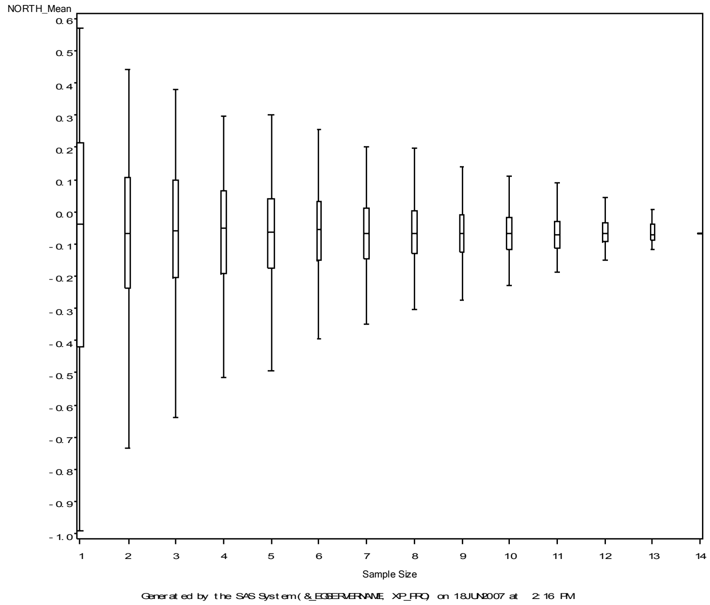
ASPECT-NORTHNESS



POLY1



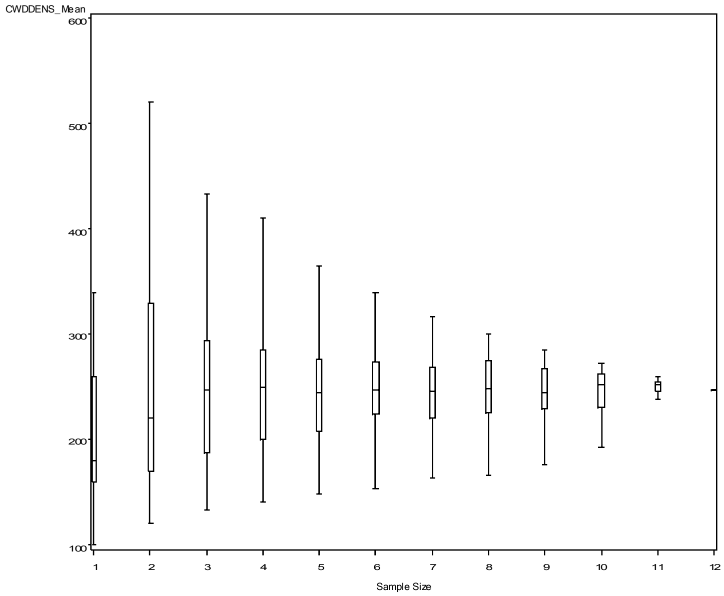
POLY21



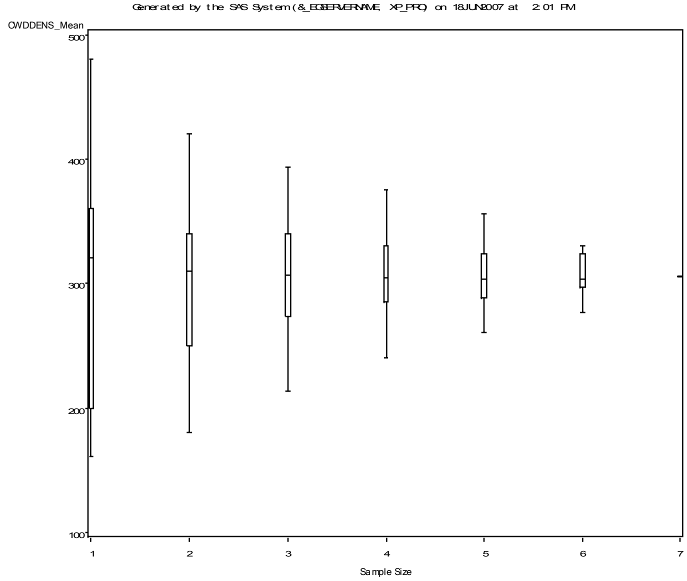
NORTH_Mean
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
-1.0
1 2 3 4 5 6 7 8 9 10 11 12 13 14
Sample Size

POLY25

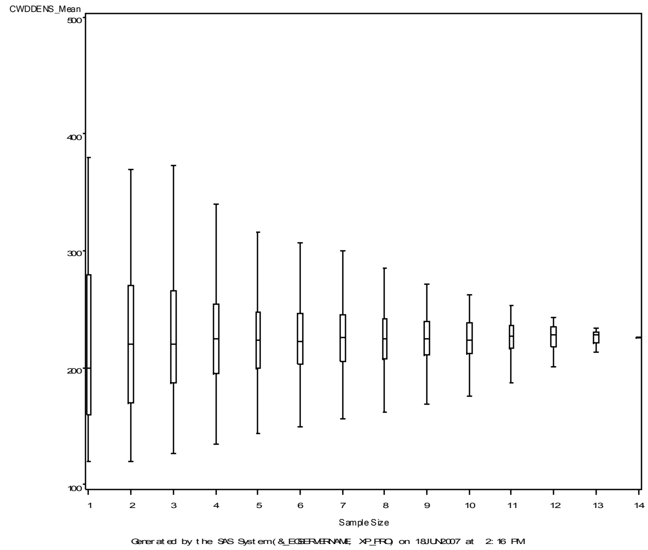
COARSE WOODY DEBRIS – DENSITY



POLY1

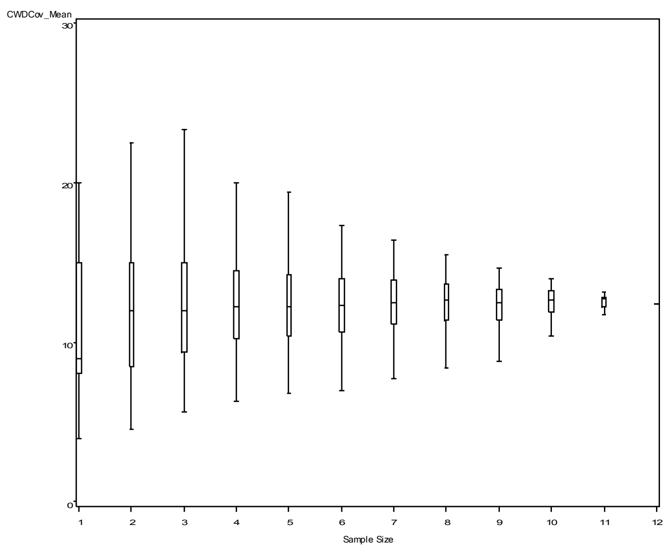


POLY21

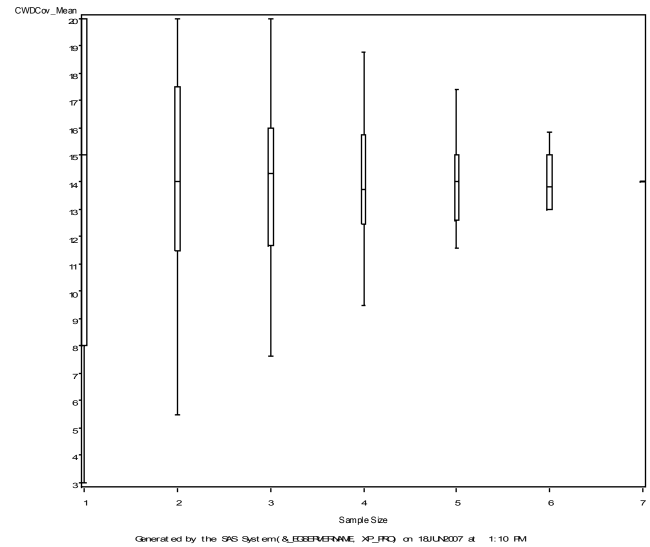


POLY 25

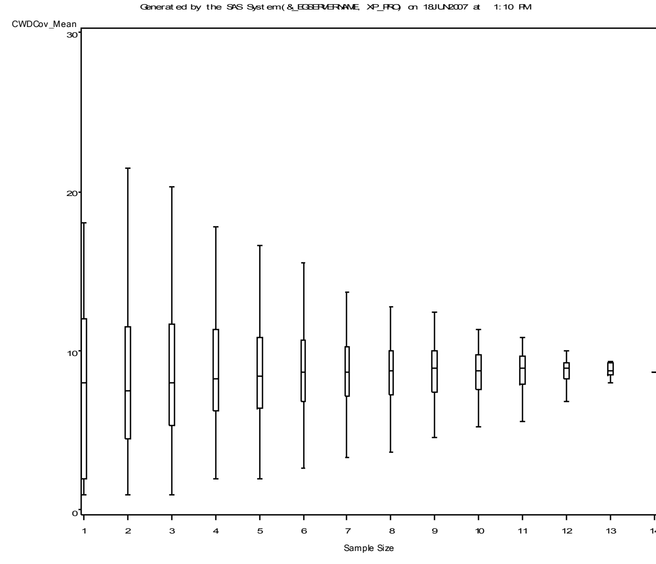
COARSE WOODY DEBRIS – PERCENT COVER



POLY 1

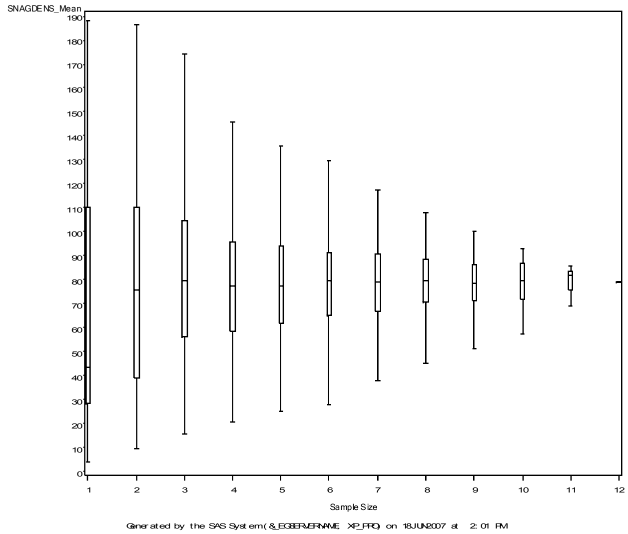


POLY21

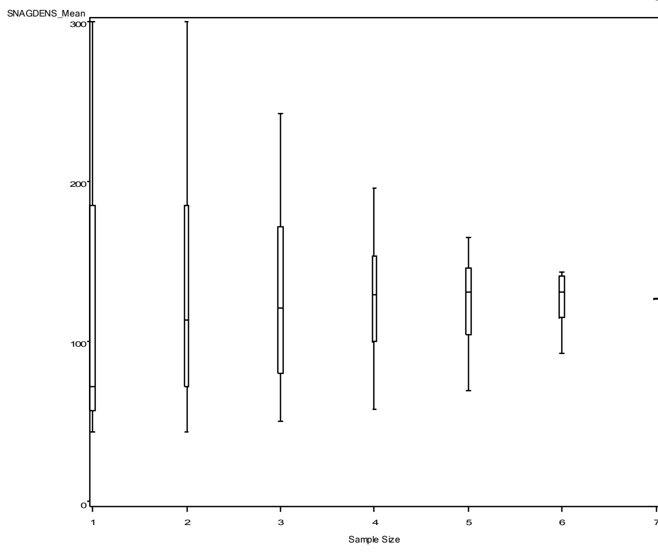


POLY25

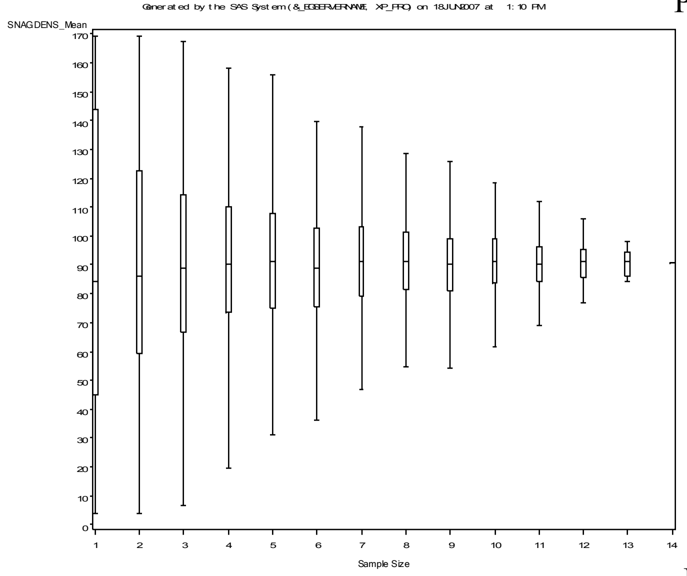
SNAG DENSITY



POLY1

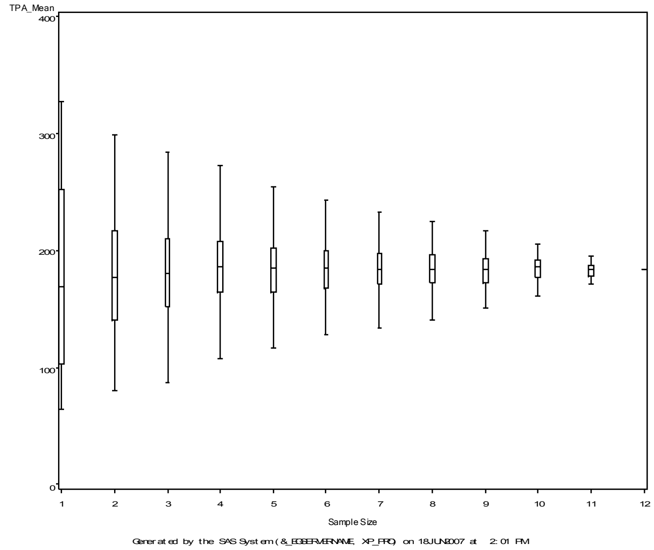


POLY21

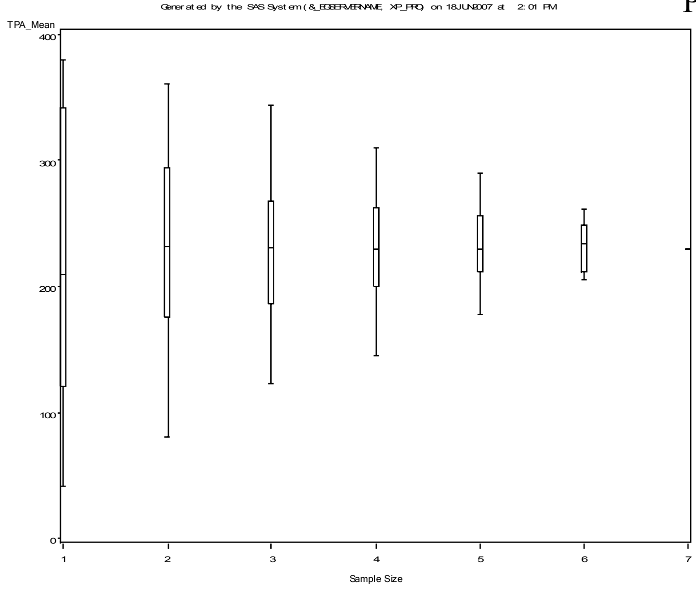


POLY25

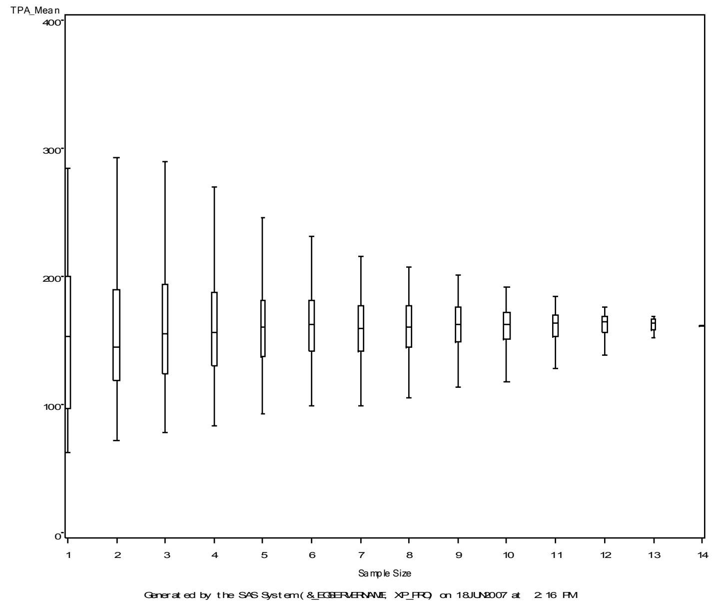
TREES PER ACRE



POLY1

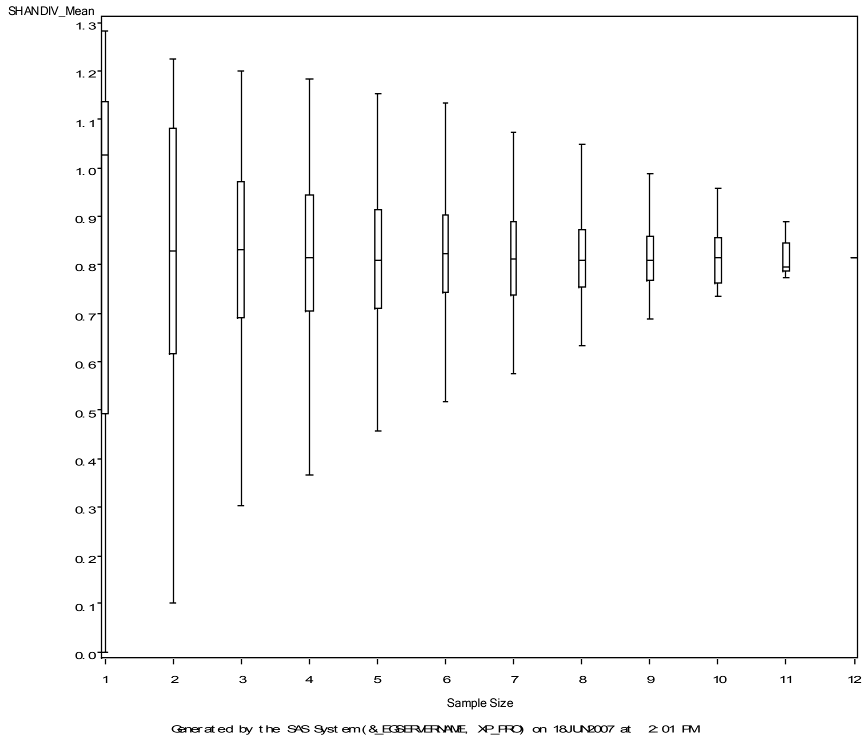


POLY21

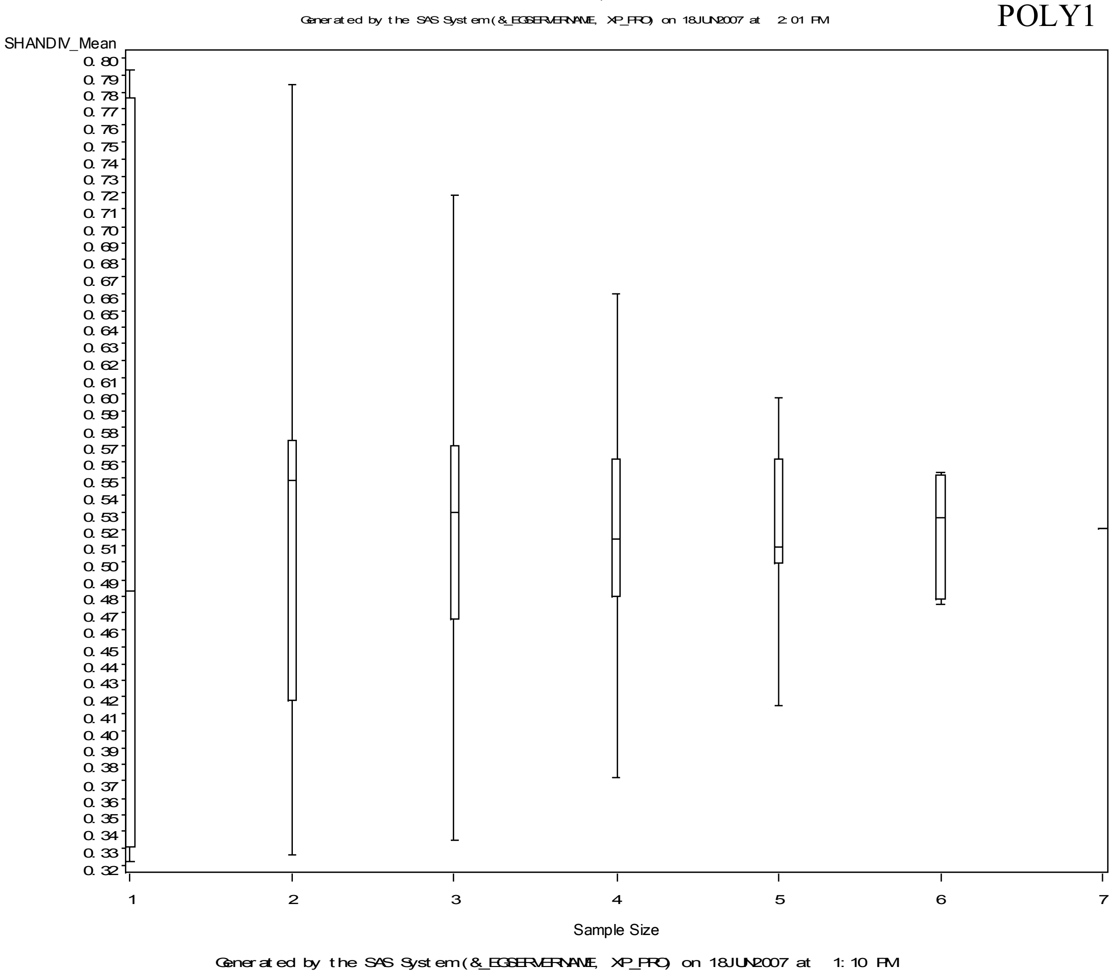

TPA_Mean
400
300
200
100
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14
Sample Size
Generated by the SAS System(&_EGSERVERNAME, XP_PRO) on 18JUN2007 at 2:16 PM

POLY25

SHANNON'S DIVERSITY INDEX OF TREE SPECIES

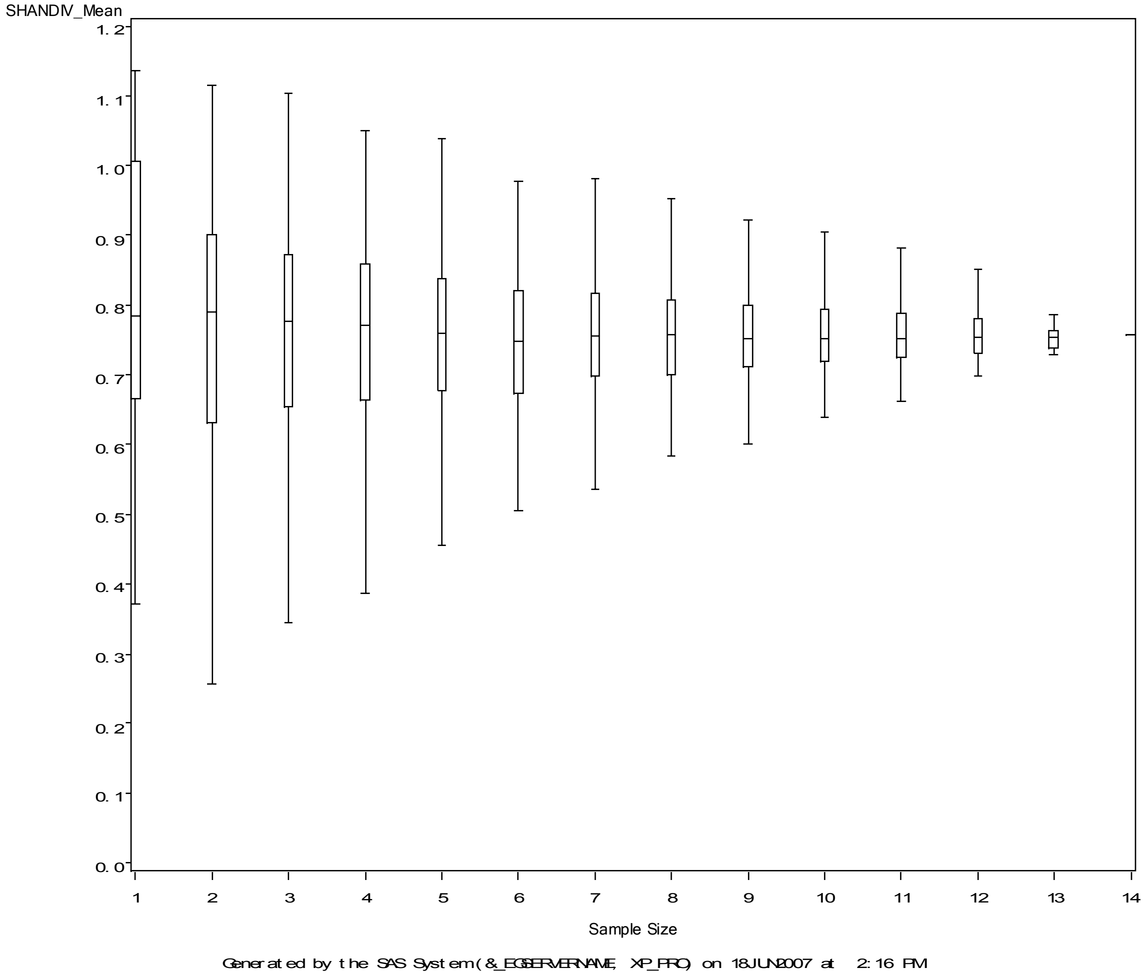


POLY1



POLY21

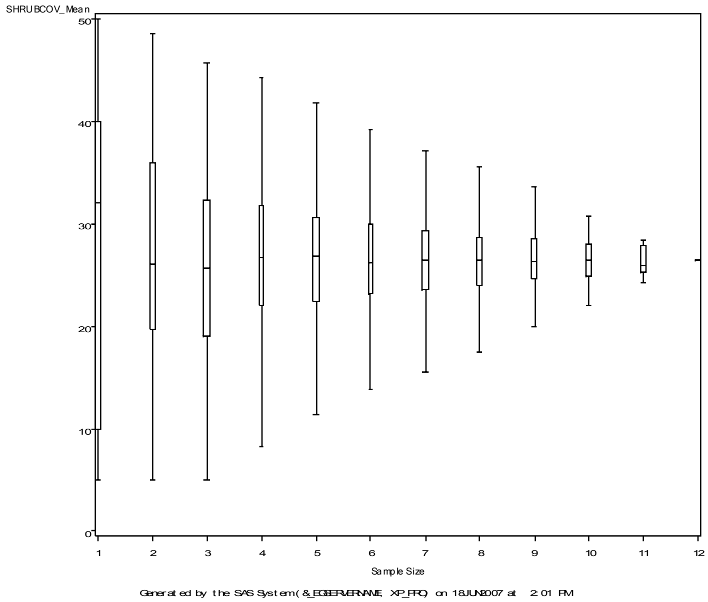
SHANNON'S DIVERSITY INDEX OF TREE SPECIES (CONTINUED)



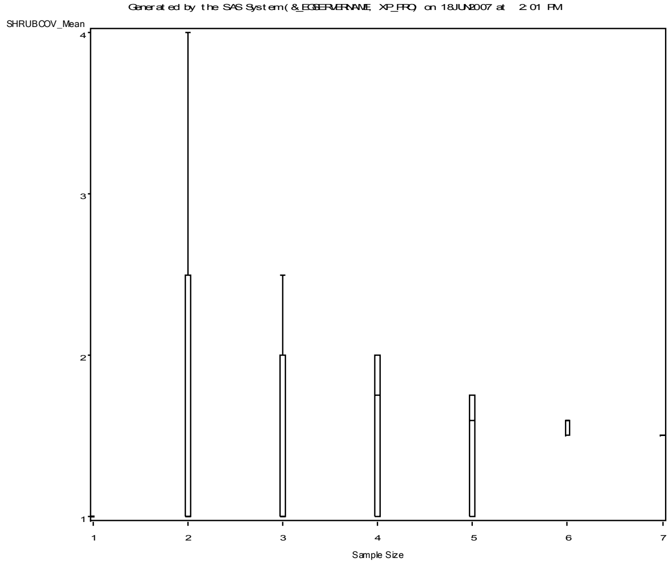
POLY

25

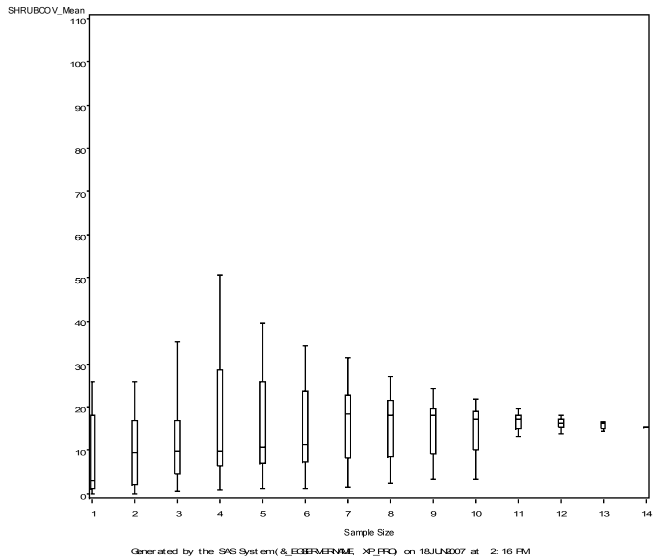
SHRUB PERCENT COVER



POLY1

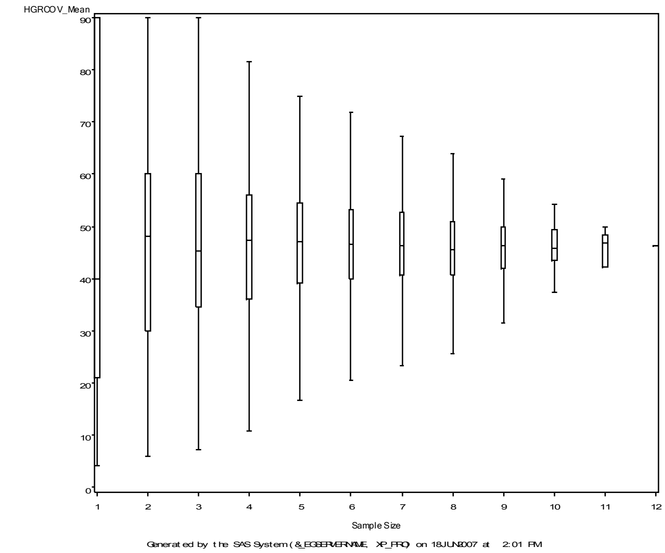


POLY21

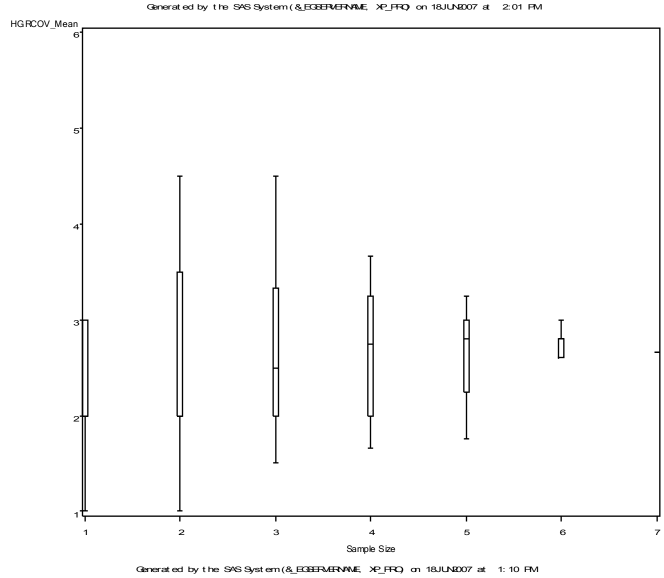

SHRUBCOV_Mean
110
100
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Sample Size

POLY25

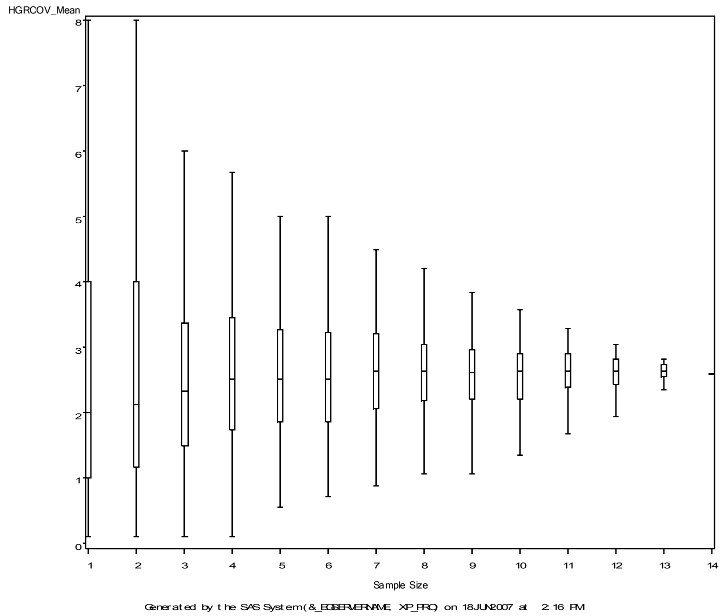
HERB & GRASS PERCENT COVER



POLY1

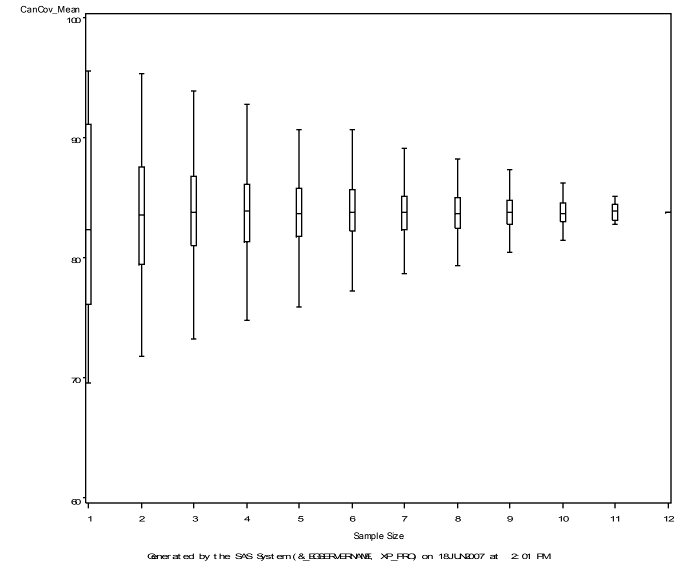


POLY21

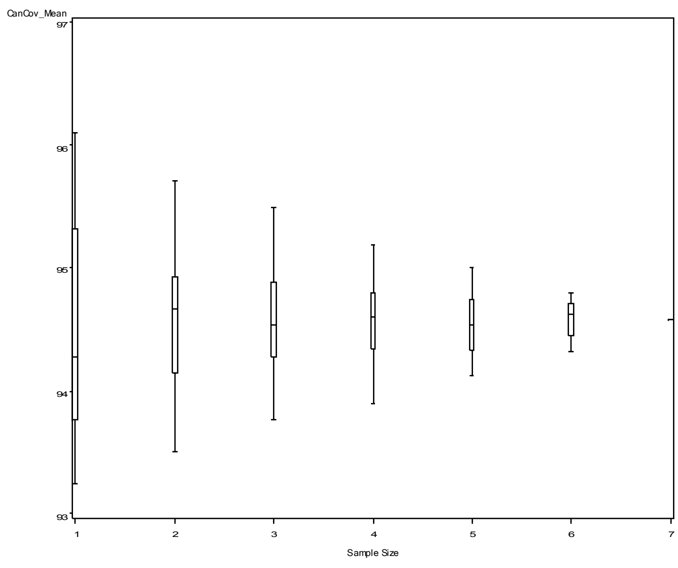

HGRCOV_Mean
Sample Size
Generated by the SAS System (&_EGSERVERNAME, XP_PRO) on 18JUN2007 at 2:16 PM

POLY25

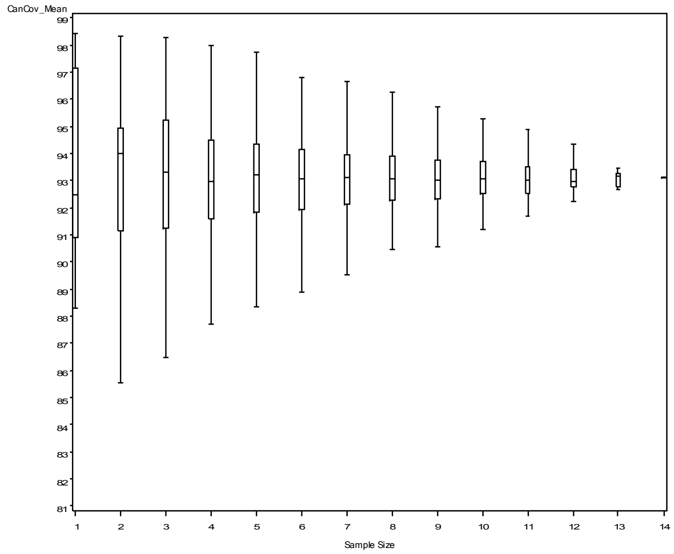
CANOPY COVER



POLY1



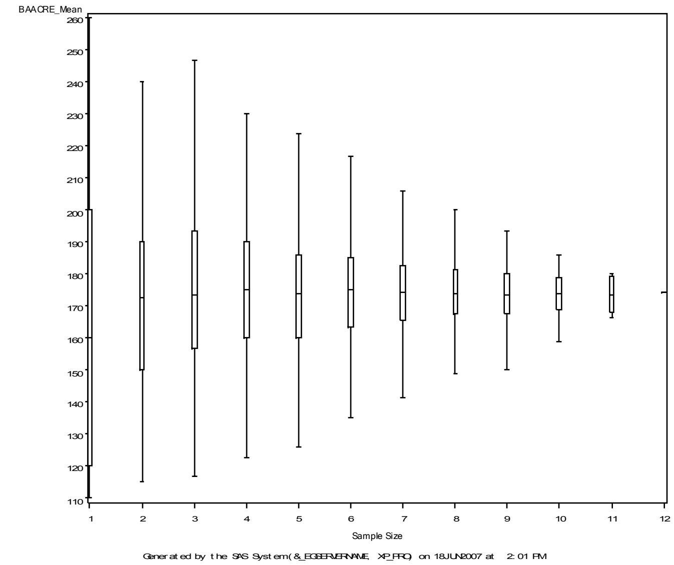
POLY21



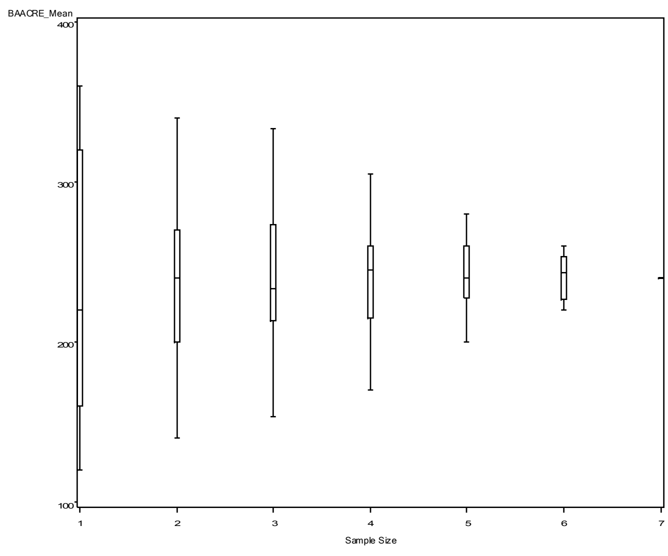
Generated by the SAS System(&_EGSERVERNAME, XP_PRO) on 18JUN2007 at 2:16 PM

POLY25

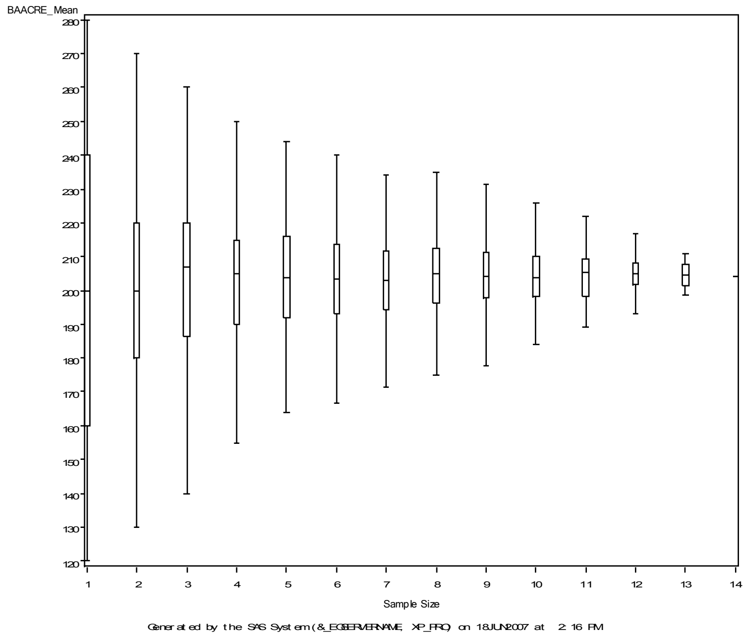
BASAL AREA PER ACRE



POLY1



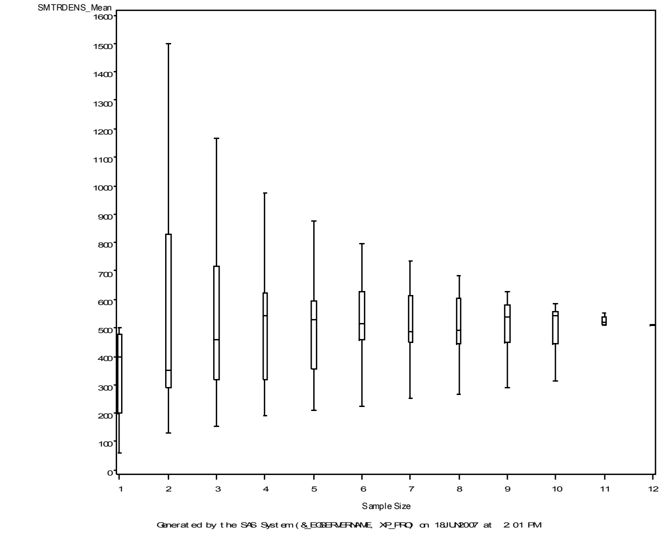
POLY21



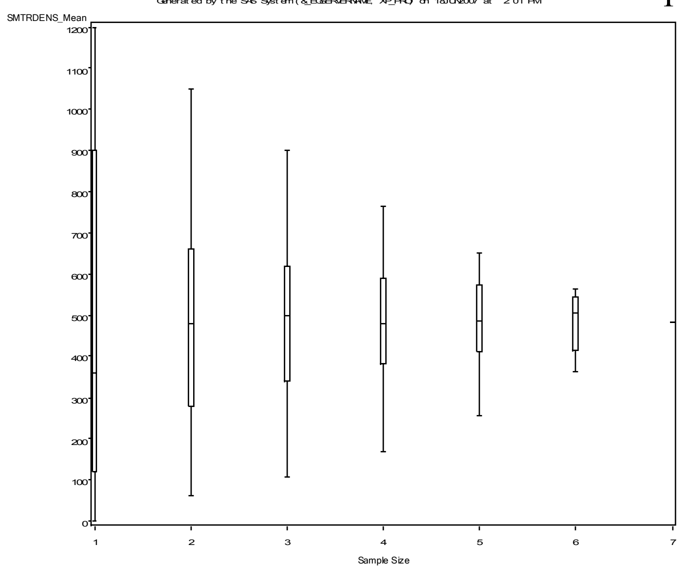
BAACRE_Mean
280
270
260
250
240
230
220
210
200
190
180
170
160
150
140
130
120
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Sample Size

POLY25

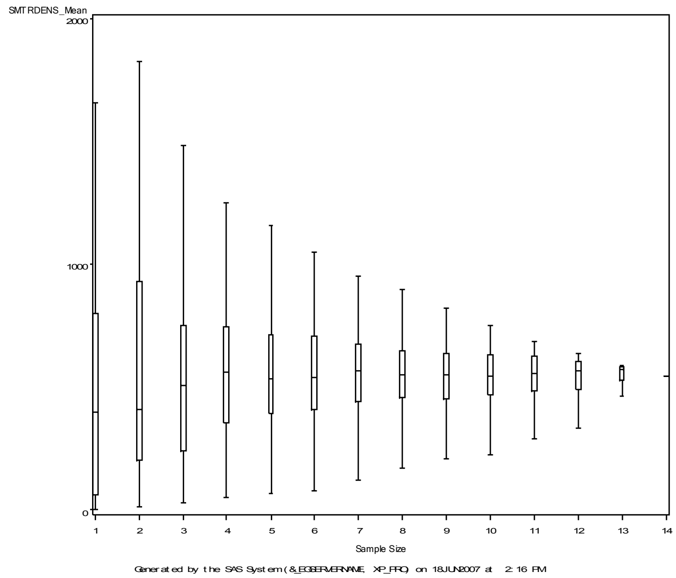
SMALL TREE DENSITY



POLY1

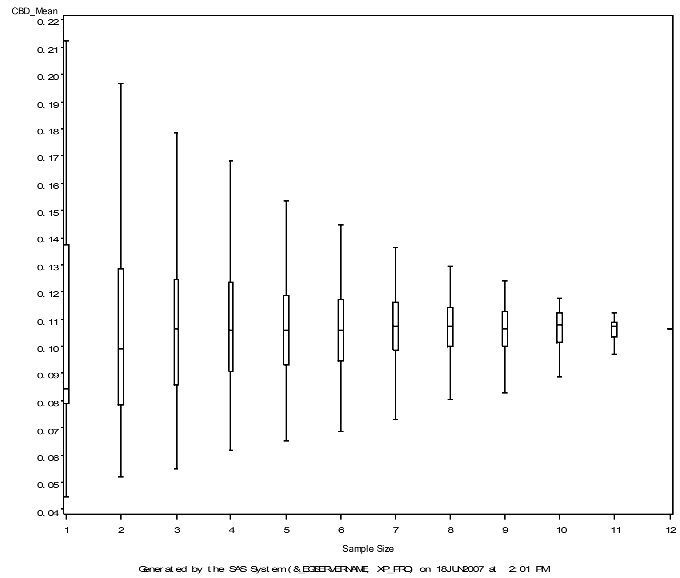


POLY21

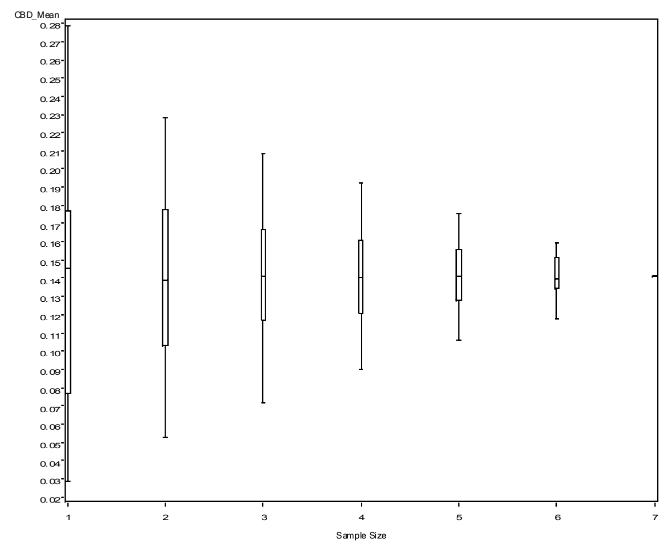

SMTRDENS_Mean
2000
1000
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Sample Size
Generated by the SAS System (&_EGSERVERNAME, XP_PRO) on 18JUN2007 at 2:16 PM

POLY25

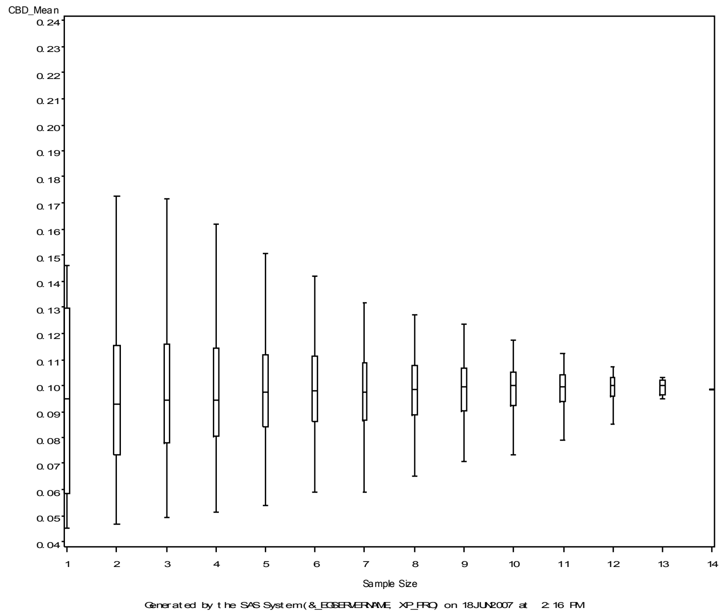
CANOPY BULK DENSITY



POLY1

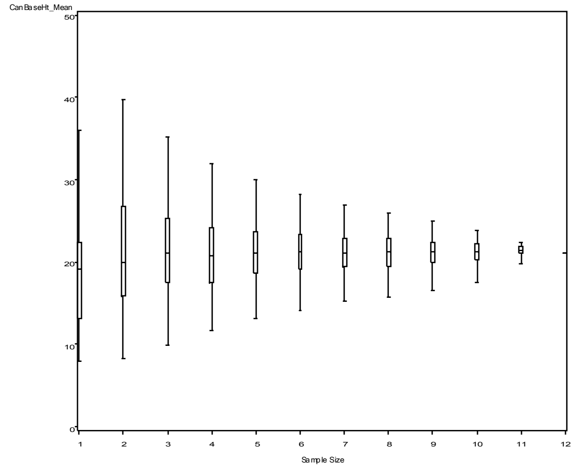


POLY21

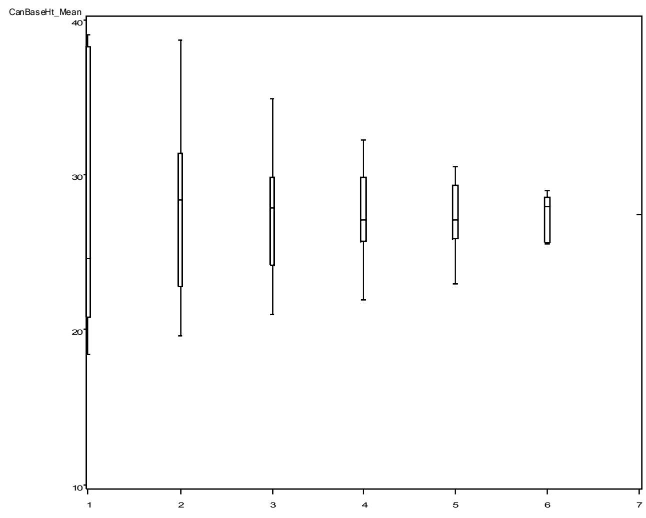

CBD_Mean
0.24
0.23
0.22
0.21
0.20
0.19
0.18
0.17
0.16
0.15
0.14
0.13
0.12
0.11
0.10
0.09
0.08
0.07
0.06
0.05
0.04
1 2 3 4 5 6 7 8 9 10 11 12 13 14
Sample Size

POLY25

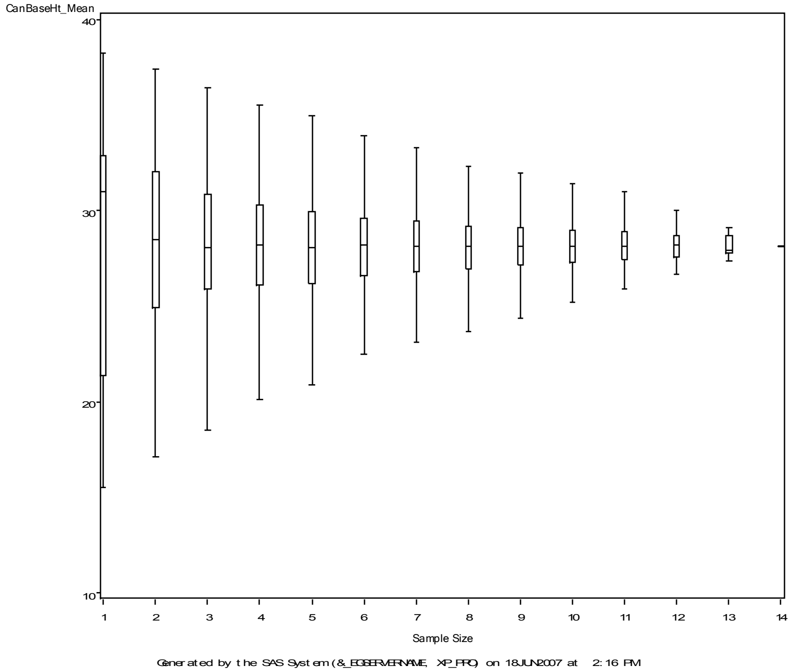
CANOPY BASE HEIGHT



POLY1

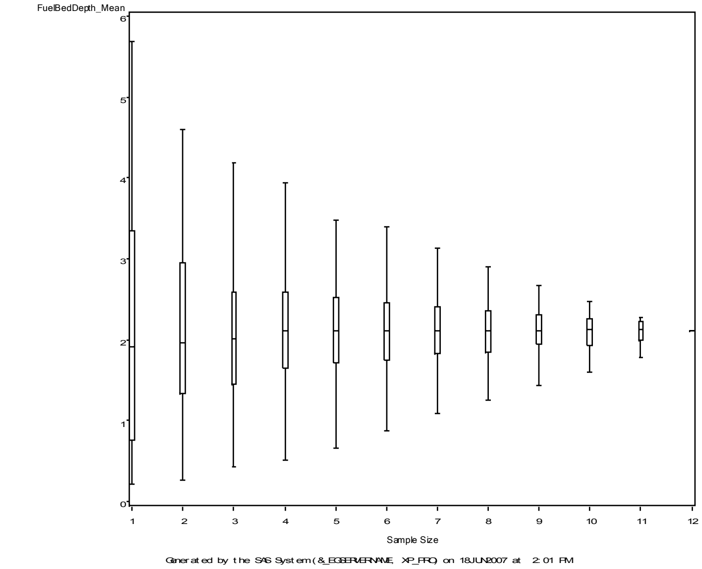


POLY21

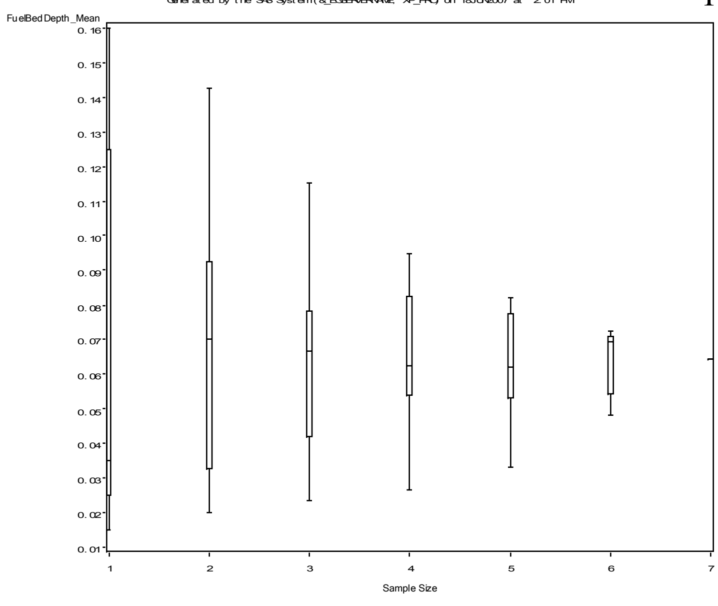

CanBaseHt_Mean
40
30
20
10
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Sample Size
Generated by the SAS System (&_EGSERVERNAME, XP_PRO) on 18JUN2007 at 2:16 PM

POLY25

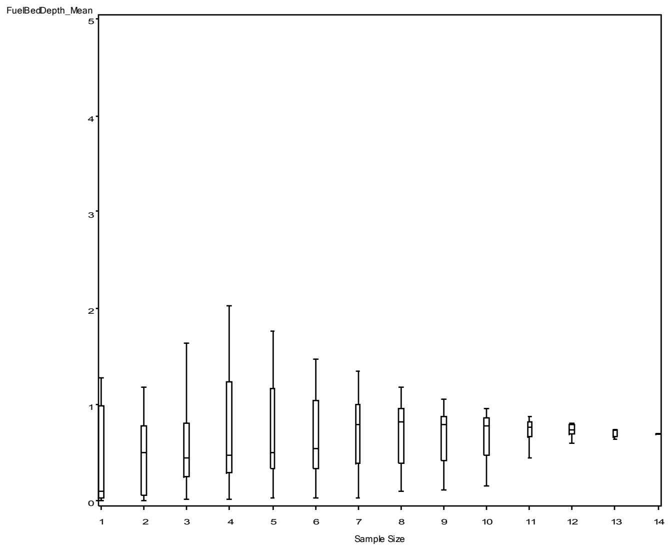
FUEL BED DEPTH



POLY1



POLY21



Generated by the SAS System (&_EGSERVERNAME, XP_PRO) on 18JUN2007 at 2:16 PM

POLY25